School of Mining Engineering

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

THE APPLICATION OF GEOSTATISTICS IN THE OPTIMIZATION OF THE NUMBER 5 SEAM EXTRACTION : A KLIPSPRUIT COLLIERY CASE STUDY

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 2020

DECLARATION

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ABSTRACT

The Number 5 Seam of the Witbank coal fields is the upper most coal seam of the sequence hosting different qualities of coal at different locations. With the seam being the upper most, it has areas where it is affected by erosion and other areas where the limit of weathering extends into the coal seam; this needs to be taken into consideration when modelling this seam.

The Minex software is widely used for the modelling and estimation of coal resources in the coal mining industry. The Software uses General purpose (Growth Algorithm), Ordinary Kriging and the Inverse distance as geospatial estimation methods. These methods produce geostatistical estimates of unknown values at unsampled locations within the study area using the laboratory data and geological information received from borehole logs; this is achieved through the process of gridding using the modelers estimation method of choice.

An in-depth understanding of what each method entails is imperative for the user to produce representative estimations in locations where data does not exist. The knowledge of the geological factors affecting a coal seam plays a major role in selecting the optimal method to be used for the estimation.

This research project explores the different estimation methods in Minex through gridding the Number 5 Seam at Klipspruit South. Each method then used to do point estimations in locations where values are known for the

comparison as to which estimation method yields results closest to the known values. Based on the data used and the analysis of the results on the different estimation methodologies, the inverse distance weighting method produces estimates closest to the known values.

Using the estimates derived from the inverse distance weighting method, two mining extraction methods (composite and selective mining) of the coal seam are assessed. Concluding that mining of the coal seam as composite yields best financial results with the current configuration of the Phola coal handling and processing plant.

DEDICATION

In Memory of my father, the late Mr Mndeni Solly Maseko, though he is not here to see where his motivation has led me to be today, his teachings lives on in me.

In appreciation of my beautiful kids Thembelihle, Thandolwethu and Sibusiso Maseko, my mother, Busi Yende, and my siblings for the faith they portrayed in me and their patience with me during the time I did this research.

ACKNOWLEDGMENTS

I would like to extend my gratitude to South 32 (PTY) Ltd for funding my studies and giving me permission to use and publish the data for Klipspruit Colliery to complete this project. I thank my supervisor Prof RCA Minnitt for his guidance and patience with me when I contracted the Corona Virus pushing me to complete this project. Mr Johann Conradie, the Chief Geologist at Klipspruit Colliery has been of great assistance with the technicalities of the software used for geological modelling, this is highly appreciated.

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1 Introduction

Coal plays a significant role in electricity generation and the fossil fuel industry and is thus in high demand globally. Meeting this demand is rooted in the understanding of the Coal Resources that coal mining companies have developed. Coal is a complex fuel in that it is made up of eight different variables which determine the mineability of the coal seam and marketability of the coal product.

These variables are the seam thickness (ST), Relative density (RD), Calorific Value (CV), Ash content (Ash), inherent moisture (IM), Volatile matter (VM), Total sulphur (TS) and Total Phosphorus content (TP). Each of these variables are correlated to the other to some degree, and these determine the thermal and marketing characteristics of the coal as well as its value per tonne.

Coal analyses may be presented in the form of “proximate” and “ultimate” analyses, whose analytical conditions are prescribed by organizations such as the American Society for Testing and Materials (ASTM). A typical proximate analysis includes the moisture, ash, volatile matter, and fixed carbon contents (Fixed carbon is the material, other than ash, that does not vaporize when heated in the absence of air).

1.1 Research study objective

Klipspruit Colliery extracts bituminous coal primarily for the export market which is processed either by washing or blending to customer specifications. For this reason, an in depth understanding of the coal quality variables and ways in which they can be used to extract and process the coal to meet the customer specifications is imperative.

The proximate and the washability analysis results for the boreholes at the KPSS show that the Number 5 Seam in this area is of better quality, this study needs to explore the possibility of extracting the KPSS Number 5 Seam as a primarily export high-grade product instead of low-grade products as was historically done at KPS Main pit and Pit BD.

1.2 Purpose of the Research Study

This research project aims to investigates three estimation methods by establishing an understanding of the theory and assumptions behind each method, through literature review and to use this insight to appreciate why these estimation methodologies are similar but not the same.

The Minex growth algorithm (MGA), Inverse Distance Weighting (IDW) and Ordinary kriging (OK) are imbedded in the Minex software used globally for Coal Resource modelling and estimation. These estimation methods enable a robust Coal Resource classification, understanding of the coal resources and inform decision making about optimal extraction of the coal using borehole data and analysis.

This study further aims to delineate areas where the coal has been affected by geological activities such as weathering and erosion to ensure optimal estimation of the mineable coal resources (MCR) per geological domain.

1.3 Research Background

Klipspruit colliery is one of five South32 (PTY) Ltd operations managed independently by South Africa Energy Coal known as SAEC ((South Africa Energy Coal (Pty)Ltd., 2019), The operation is an open cast mine located about 100km east of Johannesburg in the Ogies District of the Emalahleni Municipality. The operation uses a dragline, dozers, drills and shovels to expose and extract coal as schematically depicted in Figure 1.

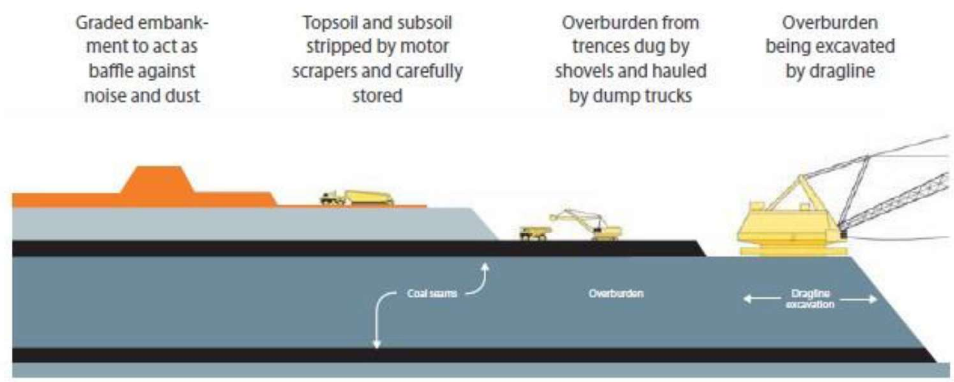


Figure 1: Simplified open cast mining (World Coal institute (2005) as cited by South African Coal Roadmap, 2011)

The coal extracted is hauled with trucks to the 16Mtpa Phola coal processing plant where it is then processed. The coal processing plant is a 50/50 joint venture between Klipspruit (KPS) and Thungela Coal. The plant produces coal for both export and domestic consumers for each company individually.

Klipspruit colliery comprises of 4 active pits namely the Bankfontein pit (BFS), KPS Main pit, R545 pit and Pit BD and two Project areas namely Klipspruit South (KPSS) and Pit H as depicted in Figure 2. The location of the KPSS study area is outlined in red in Figure 2.

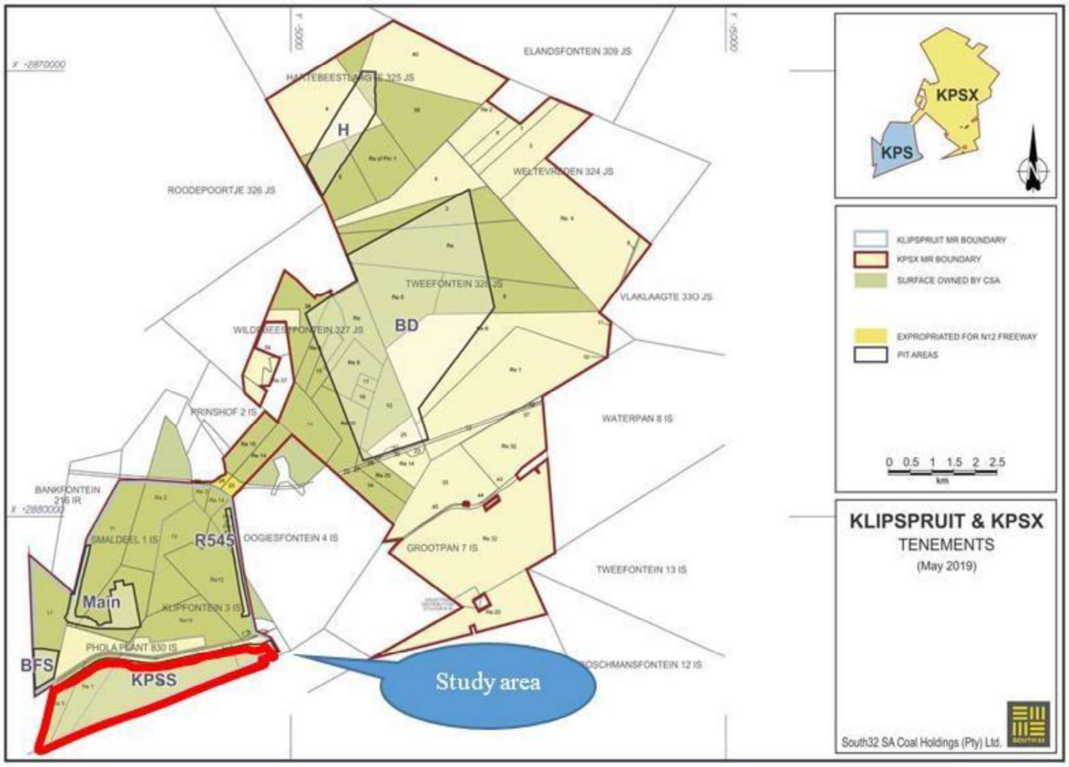


Figure 2: Klipspruit Colliery pits (Adopted from South Africa Energy Coal (Pty)Ltd., 2019).

The KPSS Project areas covers 382.8 ha south of the KPS Main pit. Over the past 20 years extensive exploration within the KPSS area was conducted leading to 309 boreholes being drilled in and around the area as depicted in Figure 3. Indicated by the red outline in Figure 3 is the KPSS eastern blocks where this study is focused as it was anticipated that the Number 5 Seam was to be extracted in this area from June 2021.

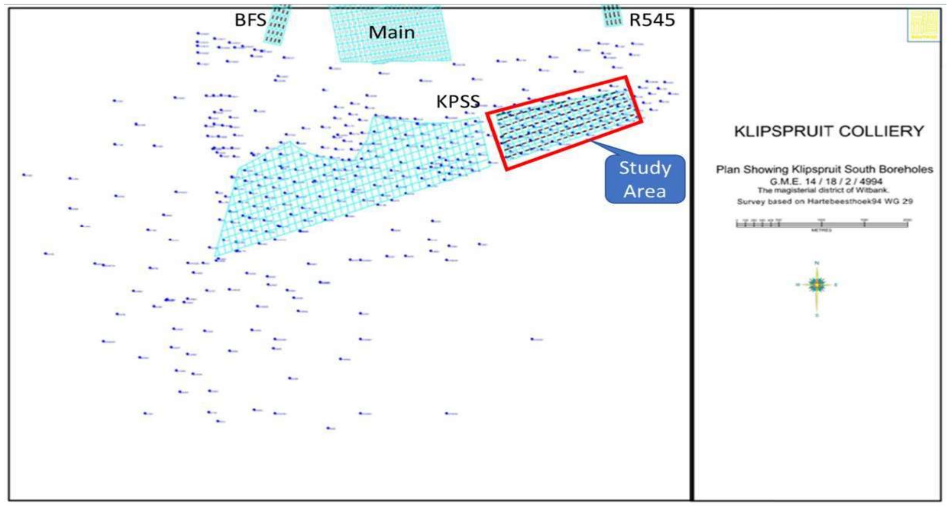


Figure 3:KPSS Project area borehole locality (Blue dots)

The scale of study area is expanded in Figure 4 showing a total of 74 boreholes all of which intercepted the Number 5 Seam coal.

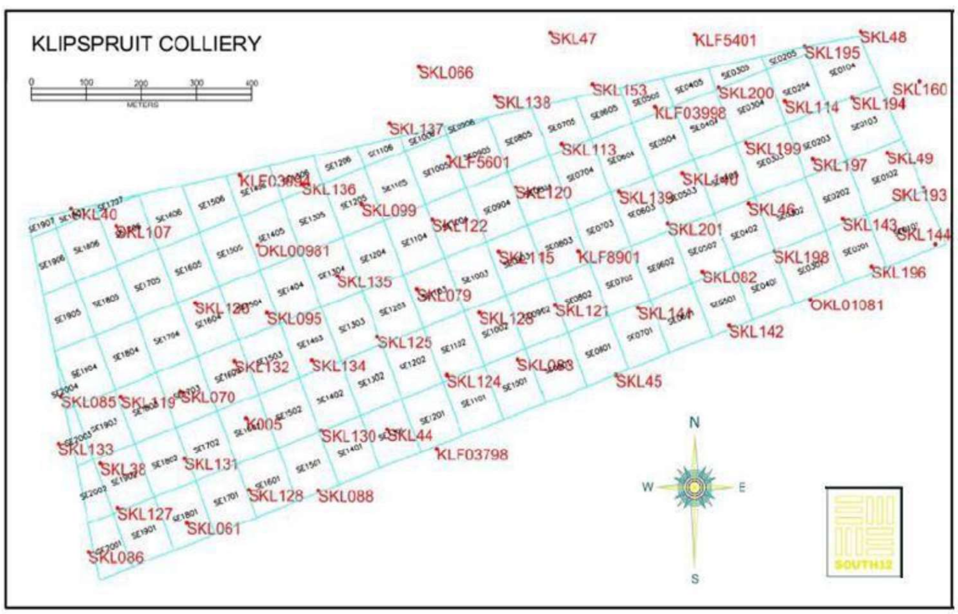


Figure 4: Boreholes drilled (red) at KPSS eastern box cut area

Figure 5 depicts the general stratigraphy of the KPSS project area as part of the Witbank Coalfields.

Figure 5: KPSS Stratigraphy (South Africa Energy Coal (Pty)Ltd., 2019)

Lying south of KPSS is the neighbouring Goedgevonden Colliery which is a Glencore managed operation, the same stratigraphic sequence as depicted in Figure 5 exists in this operation. Goedgevonden Colliery extracts the Number 5 Seam coal primarily for their high-grade export customers.

The Number 5 Seam varies in thickness as shown in the geophysical logs in Figure 6 and Figure 7 as observed at the Main pit and Pit BD, respectively. In the geophysical logs, the Gamma, Long space density and short space density is used to identify the coal. Coal density is normally low, from 1.5 to 1.1 kg/m^3 for both long and short density scales and has a low reactivity in the gamma readings compared to the other rock types.

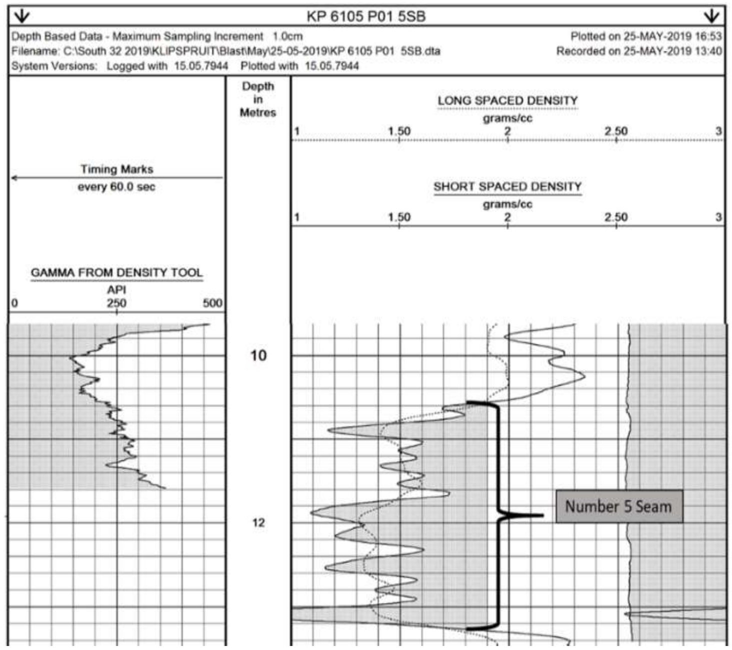


Figure 6: Geophysical log of the number 5 Seam at Main pit

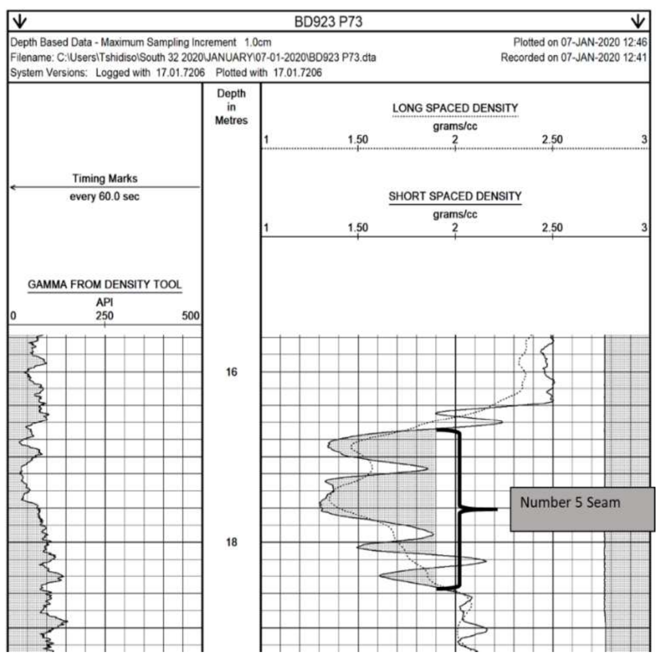
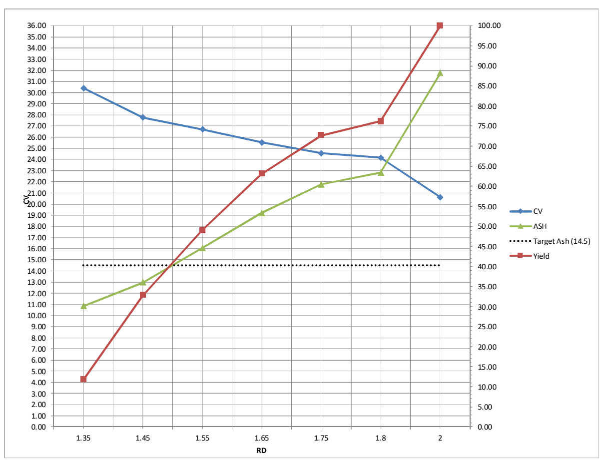


Figure 7: Geophysical log of the number 5 Seam Pit BD

The intercepted Number 5 Seam is indicated in both Figure 6 and Figure 7, it is evident in these geophysical logs that the coal at the KPS Main pit and Pit BD has many non-coal lithologies (density readings higher than 1.5 kg/m^3) intercalated with the coal (densities lower than 1.5 kg/m^3) and thus affecting the in-situ coal quality and how the coal can be processed.

As depicted in Figure 8, having these intercalations results in the coal seam having a high composite raw relative density (RD) thus should be processed at lower wash density to separate the coal from the waste and will result in low product yield.



RAW Qualities	
RD	1.61
Ash	31.75
CV	20.62
FC	43.17
IM	3.11
TS	1.14
VM	21.96

Theoretical / Borehole Yield		
Primary	Secondary	Total
40.02	36.18	76.20

Practical / Plant Yields		
Primary	Secondary	Total
32.02	32.18	64.20

Cumulative wash table																	
1.35			1.45			1.55			1.65			1.75			1.8		
ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD
10.84	30.39	11.79	12.98	27.76	32.86	16.05	26.70	49.01	19.18	25.54	63.08	21.76	24.55	72.67	22.83	24.15	76.20

Figure 8:Wash curve of the Pit BD Number 5 seam coal indicating raw qualities and product yield for high grade export wash.

Due to the low high grade export yield, the coal from Pit BD and Main pit is currently processed primarily for low-grade domestic and export markets.

Figure 9 shows a geophysical log of the KPSS Number 5 Seam taken from the exploration borehole SKL225.

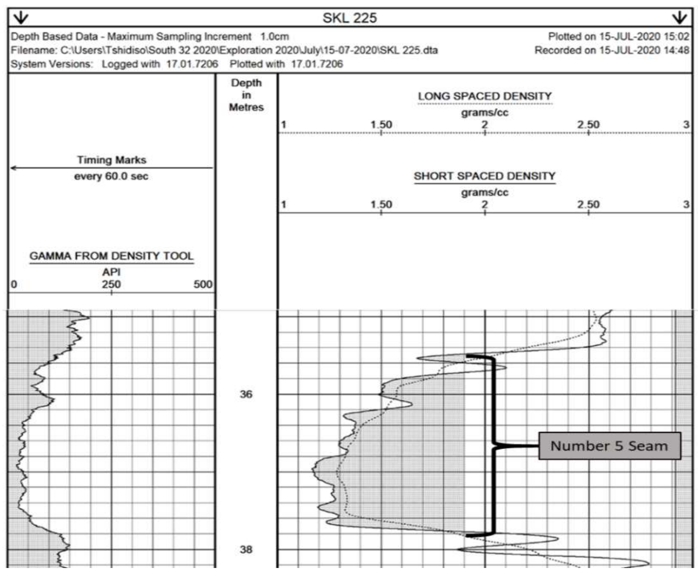
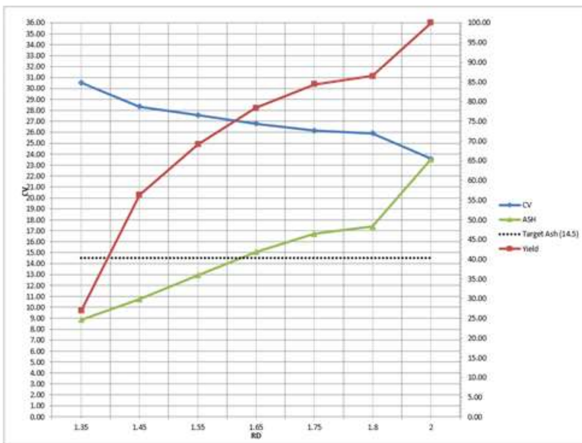


Figure 9:Geophysical log of the Number 5 Seam at KPSS

Evident on Figure 9, the intercalations observed in Figure 6 and in Figure 7 are only observed in the upper portion of the KPSS number 5 Seam, this constitute for a change in approach of the allocation, extraction and processing of the coal in this area.

The average low density readings of the Number 5 Seam shown in Figures 9, indicate that better quality (lower in-situ raw RD) coal should be expected in KPSS than that being currently mined at KPS Main pit and Pit BD (higher in-situ raw RD).

Observed on figure 10 is the wash curve for the KPSS Number 5 seam, the was curve shows that the raw qualities are better than those observed in figure 8 and the high grade product to be achieved is also higher.



RAW Qualities	
RD	1.52
Ash	23.53
CV	23.58
FC	46.16
IM	3.43
TS	1.42
VM	26.88

Theoretical / Borehole Yield		
Primary	Secondary	Total
75.02	11.51	86.53

Practical / Plant Yields		
Primary	Secondary	Total
67.02	7.51	74.53

Cumulative wash table																	
1.35			1.45			1.55			1.65			1.75			1.8		
ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD
8.86	30.53	26.82	10.73	28.35	56.29	12.92	27.57	69.12	15.05	26.78	78.40	16.71	26.15	84.37	17.39	25.90	86.53

Figure 10: Wash curve of the KPSS Number 5 seam coal indicating raw qualities and product yield for high grade export wash

Geologically the study area is not complex, however in some areas the Glauconitic sandstone overlying the Number 5 Seam is weathered such that the limit of weathering extends into the coal seam; this results in the coal seam not being recovered in some of the exploration boreholes drilled.

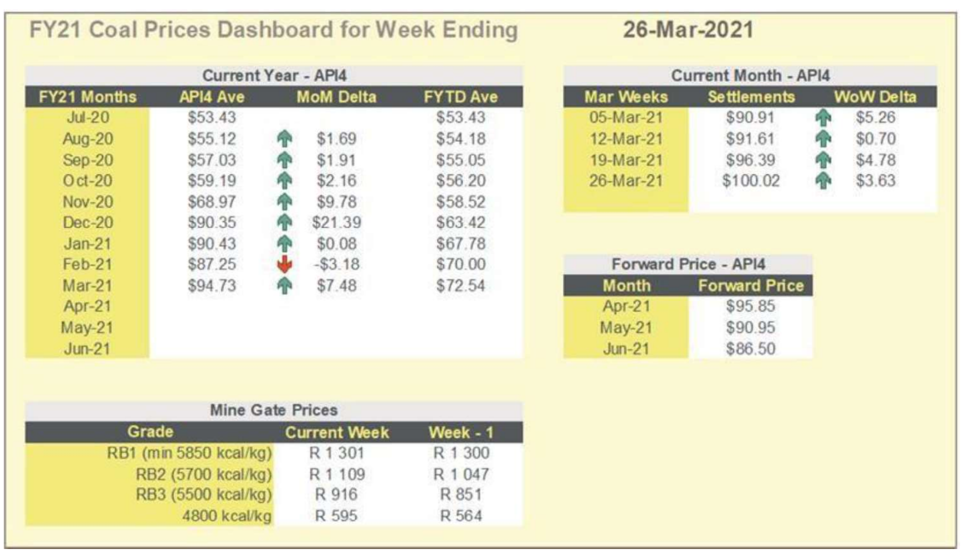
Using exploration holes, a estimation model is created which is the spatial representation of the coal hosted in the area. The model annotates the distribution of the coal seams and the qualities thereof using the geological logs and laboratory results. The laboratory results contain the washability (float and sink) analysis of the samples which is then gridded to estimate tonnages of coal that can be extracted at a specific wash density.

KPS is an export mine which produces thermal coal mainly for the export market. Using the in-situ quality and washability of the coal, the coal is either crushed, screened and blended into a specific product or washed through the processing plant to meet the specifications outlined in Table 1

Table 1: Product Specifications as required by South32 customers

		Quality Variable				
		Ash (%)	CV (Mj/Kg)	Volatile Matter (VM)	Total Sulphur (TS)	Fixed Carbon (FC)
Product specification	4800 NAR	26.10	20.10	19.9	0.75	45.5
	5500 NAR	19.40	23.90	21.7	0.56	51.1
	5800 NAR	17.00	25.20	22.5	0.53	53
	5950 NAR	15.70	25.80	22.8	0.46	54.3
	6000 NAR	14.10	26.00	23.4	0.44	54.7

The price of coal increases with the increased quality of the coal (the 6000 NAR being of the highest price and the 4800 NAR the lowest). Figure 11 shows the coal price per product as at 26 March 2021.


FY21 Coal Prices Dashboard for Week Ending 26-Mar-2021

Current Year - API4

FY21 Months	API4 Ave	MoM Delta	FYTD Ave
Jul-20	$53.43		$53.43
Aug-20	$55.12	$1.69	$54.18
Sep-20	$57.03	$1.91	$55.05
Oct-20	$59.19	$2.16	$56.20
Nov-20	$68.97	$9.78	$58.52
Dec-20	$90.35	$21.39	$63.42
Jan-21	$90.43	$0.08	$67.78
Feb-21	$87.25	-$3.18	$70.00
Mar-21	$94.73	$7.48	$72.54
Apr-21			
May-21			
Jun-21			

Current Month - API4

Mar Weeks	Settlements	WoW Delta
05-Mar-21	$90.91	$5.26
12-Mar-21	$91.61	$0.70
19-Mar-21	$96.39	$4.78
26-Mar-21	$100.02	$3.63

Forward Price - API4

Month	Forward Price
Apr-21	$95.85
May-21	$90.95
Jun-21	$86.50

Mine Gate Prices

Grade	Current Week	Week - 1
RB1 (min 5850 kcal/kg)	R 1 301	R 1 300
RB2 (5700 kcal/kg)	R 1 109	R 1 047
RB3 (5500 kcal/kg)	R 916	R 851
4800 kcal/kg	R 595	R 564

Figure 11: Coal prices as at 26 March 2021 (South32 (PTY) LTD, 2021)

KPS has the market and produces all the products mentioned in Table 1, the Number 5 Seam is being blended mostly into the 4800 NAR and sometimes, to the 5500 NAR products. As observed in Figure 11, the above mentioned products do not yield much revenue.

1.4 Research Motivation

Klipspruit Colliery, like most of the mines in the Witbank coalfield uses Minex for Coal Resource modelling and estimation. Though there are other estimation methods offered in Minex such as OK and IDW, the most commonly used estimation method in the coal mining industry is the MGA as it is believed to best represent the data analysis and gridding of the stratified deposit.

Unlike the KPS Main pit and Pit BD, borehole logs, geophysical logs, proximate analysis and washability analysis of the KPSS Number 5 Seam coal show a potential of this coal being processed primarily for the high-grade thermal export market.

1.5 Problem Statement

Due to several intercalations of shale and sandstone observed at KPS main pit and Pit BD as shown in Figure 6 and Figure 7, the Number 5 Seam coal is defined as low-grade coal at Klipspruit Colliery with in-situ calorific values ranging between 17 and 22 MJ/Kg. The exploration drilling at KPSS has shown that the Number 5 Seam coal at KPSS has less coal intercalated with sandstone and shale than at KPS Main pit and Pit BD as observed in the geophysical log of the seam and 21 – 26 MJ/Kg composite raw CV.

The high-quality coal beds in the KPSS area hold much potential as a very marketable export quality product which this research study aims to investigate, prove and promote for the extraction of the Number 5 Seam. The distribution of areas of high CV and low Ash delineated using a geostatistical approach and once this is achieved a selective mining approach will be explored.

1.6 Assumptions

The study assumes that the boreholes to be used have been logged and sampled according to the South32 Standard Operating Procedure and that sampling standard reference materials, blanks and duplicates followed by a QA/QC analysis of the data has been completed. Though studies are under way regarding how the coal handling plant can be re-configured to process weathered coal, this research study assumes that these studies has not been completed. Furthermore, it may be assumed that the identification of different domains of geological homogeneity in the study area will result in the stationarity of the random variables being achieved.

1.7 Research Methods and Sources

Seven additional exploration holes were drilled in the study area from February to July 2020, these boreholes were logged and sampled. The samples were taken to a South African National Accreditation System (SANAS) accredited laboratory where the proximate and washability analysis at different wash densities were done. The washability analysis returns results for CV, IM, Ash, VM, FC, TS and Yield (YL) at incremental density values from 1.35 to 1.8 kg/m^3. More boreholes exist in the study area and captured in the geology database, these will be used in conjunction with the new holes for the study.

The coal modelling software has the three estimation methods embedded in it will be used to create coal quality prediction plans from known borehole data. Cross validation was done using the known data from the laboratory, borehole logs and the estimates thereof for each estimation method. The aim of using all three approaches was to determine which of the approaches yields the most realistic results; The Minex software takes the exploration borehole logs, the laboratory results and generates grids based on the estimation method selected which defines the grade and tonnage distribution of the coal seam. The software also interpolates the structural characteristics of the lithologies as defined by the borehole logs to create a geological model.

The method with the most accurate results will be used for further investigations. The estimation methods was used to quantify the tonnages of the resources that meet the quality requirements for high-grade export product extraction. This was achieved through a geostatistical evaluation of the main coal quality variables such as ST, CV and Ash while taking into consideration the TS in the coal seam.

1.8 Structure of the Research Report

The research study report is broken down into sections as outlined below:

- **Introduction**

Introduces the company, the research objectives, purpose of the study, the background of the study, problem statement, assumptions considered in the research study and methodology.

- **Literature Review**

Investigates work done by previous researchers in the subject matter presented in the research.

- **KPS Geology**

Discusses the local geology and exploratory data analysis of the data being used for the research study.

- **Resource Estimation in Minex**

Explores the different estimation techniques embedded in the Minex software.

- **Establishing the optimal coal extraction method**

Introduces two possible mining methods that can be used for the extraction of the KPS Number 5 Seam coal while giving detail on the distribution of the coal seam and coal quality variables.

- **Number 5 Seam Extraction in the P3 Domain**

Narrows down the research study area to the P3 domain based on coal qualities and thickness and explore both mining methods and financial implications.

- **Conclusions**

Concludes the findings of the research study

- **References**

Lists the sources used in the research study

2 Literature Review

This chapter briefly introduces the Witbank Coal fields the geology thereof and the coal seams of economic interests. Estimation methods and data analysis is also discussed as they influence Coal Resource classification which concludes the chapter.

2.1 The Witbank Coal Field

Named after the City of Witbank, which was changed to Emalahleni in 2006, meaning the city of coal, the Witbank coalfield is situated in the northern part of the Karoo basin as indicated by Figure 12 (Hancox & Götz, 2014). This coalfield is regarded as one of the most economically important coal resources in South Africa currently being exploited (Wheeler, 2015).

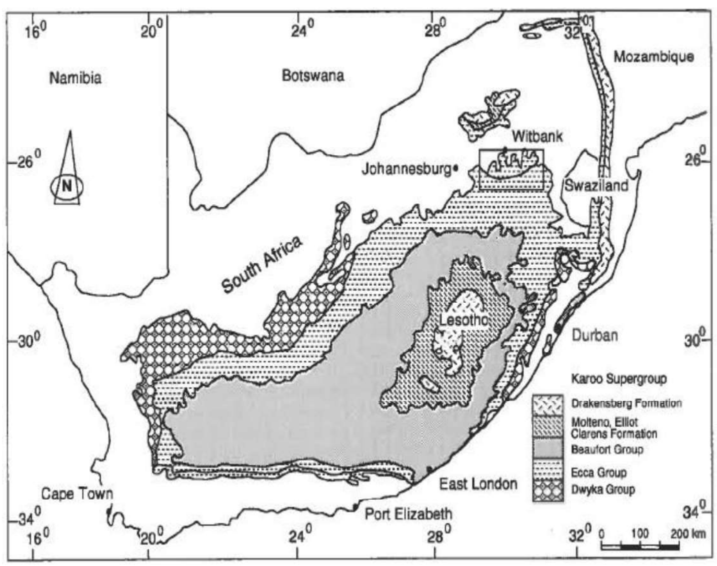


Figure 12: : Locality of the Witbank Coalfields (Venter & Cairncross, 1995)

Figure 13 shows the North – South and the East – West cross sections of the Witbank Coalfield, the major structures and lithological groups.

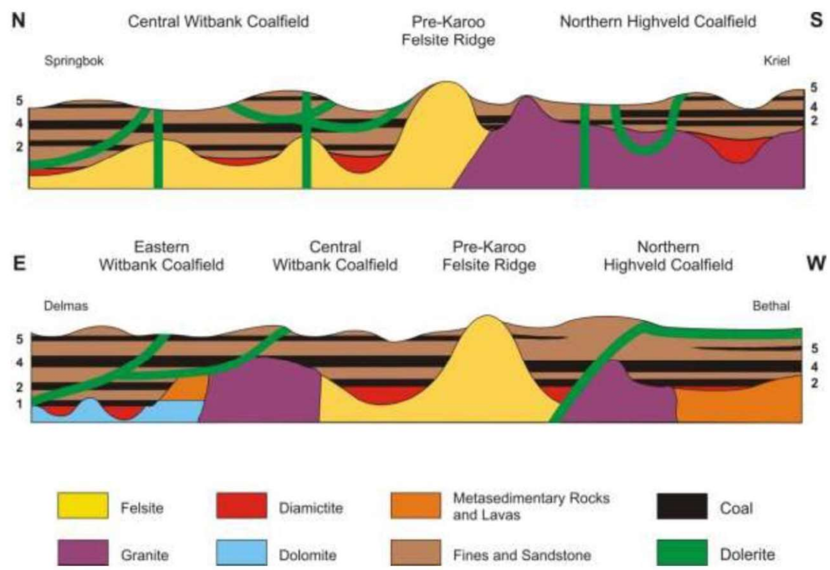


Figure 13: Cross Sections of the Witbank Coalfield (Hancox & Götz, 2014)

The coal seams mentioned above are characterized as follows (Jeffrey, 2005):

- **No. 1 Seam**: 0–3 m, patchily developed due to Pre-Karoo topography, source of high quality coal suitable for export after beneficiation and can be mined separately due to low phosphorus content as metallurgical feedstock;
- **No. 2 Seam**: 4.5–20 m, up to 6 quality zones, most economically important with 3 basal zones mined mainly for low ash metallurgical coal and export steam coal;
- **No. 3 Seam**: 0.5 m, high quality, generally uneconomic;
- **No. 4 Seam**: 2.5–6.5 m, commonly split into Nos 4A, 4 Upper, 4 Lower Seams by mudstone/siltstone partings, economically

important but lower quality than No. 2 Seam, generally mined as a power station feedstock and as domestic steam coal;

- **No. 5 Seam**: 0–2 m, erosional remnants, mined as a source of blend coking coal and for metallurgical uses especially in the central Witbank area where it is of higher quality.

The five major economically extracted coal seams are hosted in the Volksrust formation of the Karoo Supergroup, the generalized stratigraphy of the coalfield is indicated in Figure 14 (Cairncross & Cadle, 1987).

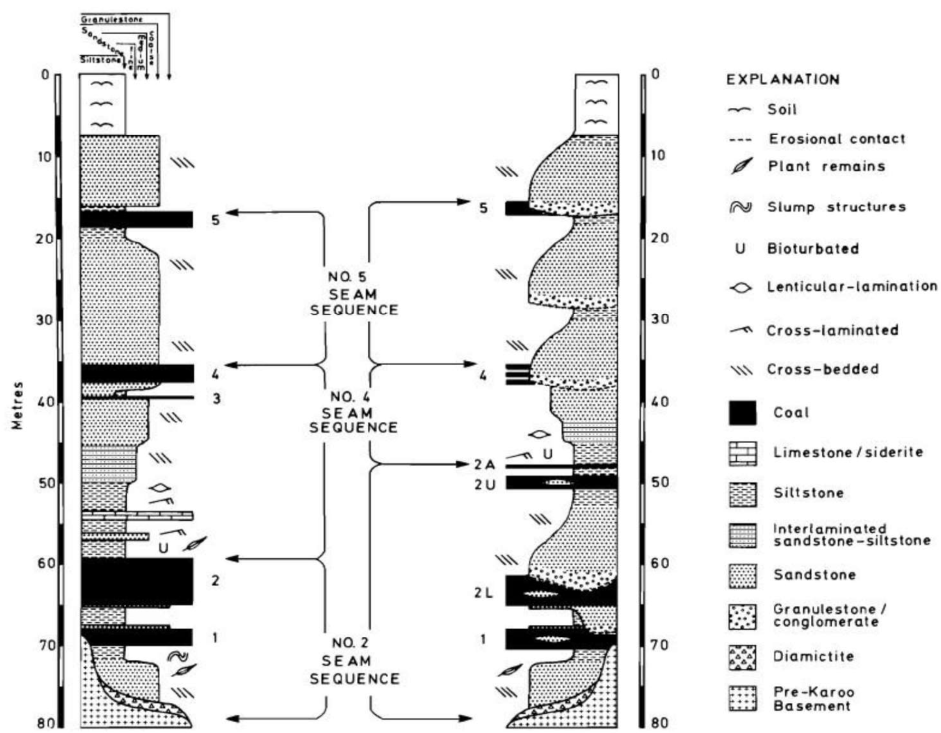


Figure 14: Generalized stratigraphy of the Witbank Coalfield indicating the coal seams (Cairncross & Cadle, 1987).

2.1 Classification of Coal Resources

Resources refer to the coal inventory of economic interests. As indicated in Figure 15 the Coal Resources can be classified into Inferred, Indicated and Measured Resources based on an increase in geoscientific knowledge and confidence of the data as per the South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves (SAMREC,2016). The classification is guided by the SAMREC code first published in the year 2000 incorporated in Section 12 of the JSE Listing Rules (Nengovhela, 2018)

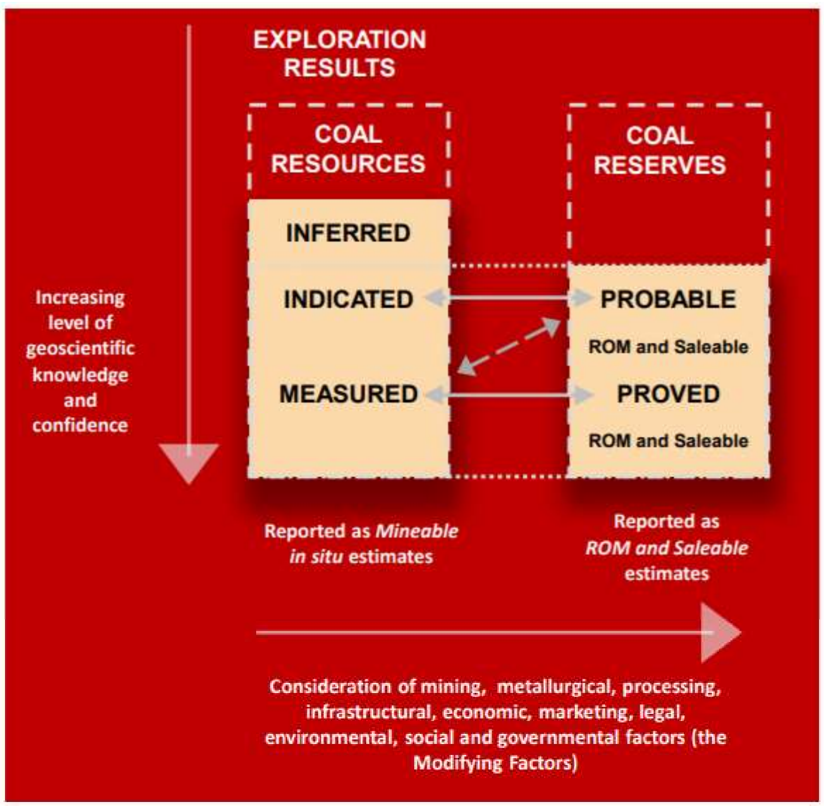


Figure 15: Relationship between Coal Resources and Coal Reserves (SAMREC, 2016)

It is observed in Figure 15 that with increased level of geological knowledge and confidence Inferred resources can be upgraded to Indicated Resources and eventually to Measured resources. The Indicated and Measured Resources can be converted to Probable and Proved reserves respectively based on the modifying factors outlined in Figure 15.

It is imperative that the Competent Person understands the meaning of the terms used for Resource classification, the SAMREC code defines these catagories as follows:

Inferred Coal Resources as "*that part of a Coal Resource for which quantity and coal quality are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient to imply but not verify geological and grade or quality continuity. An Inferred Coal Resource has a lower level of confidence than that applying to an Indicated Coal Resource and must not be converted to a Coal Reserve. It is reasonably expected that the majority of Inferred Coal Resources could be upgraded to Indicated Coal Resources with continued exploration*" (SAMREC, 2016: p 32 of 86)

Indicated Coal Resources as "*that part of a Coal Resource for which quantity, grade or quality, densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit.*

Geological evidence is derived from adequately detailed and reliable exploration, sampling and testing and is sufficient to assume geological and grade or quality continuity between points of observation.

An Indicated Coal Resource has a lower level of confidence than that applying to a Measured Coal Resource and may only be converted to a Probable Coal Reserve" (SAMREC, 2016: p 32 of 86)

Measured Coal Resources as "*that part of a Coal Resource for which quantity, grade or quality, densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit.*

Geological evidence is derived from detailed and reliable exploration, sampling and testing and is sufficient to confirm geological and grade or quality continuity between points of observation.

A Measured Coal Resource has a higher level of confidence than that applying to either an Indicated Coal Resource or an Inferred Coal Resource. It may be converted to a Proved Coal Reserve or to a Probable Mineral Reserve" (SAMREC, 2016: p 33 of 86).

Nengovhela (2018) mentions that this code was followed by the SANS 10320:2004 (currently superseded by SANS 2019) which specified horizontal data spacing distance; this standard entails that the distance between boreholes should be less than 350m, 350 – 500m, greater than 1000m and greater than 2000m for the

Measured, Indicated, Inferred and Reconnaissance resources respectively; These are depicted in Figure 16.

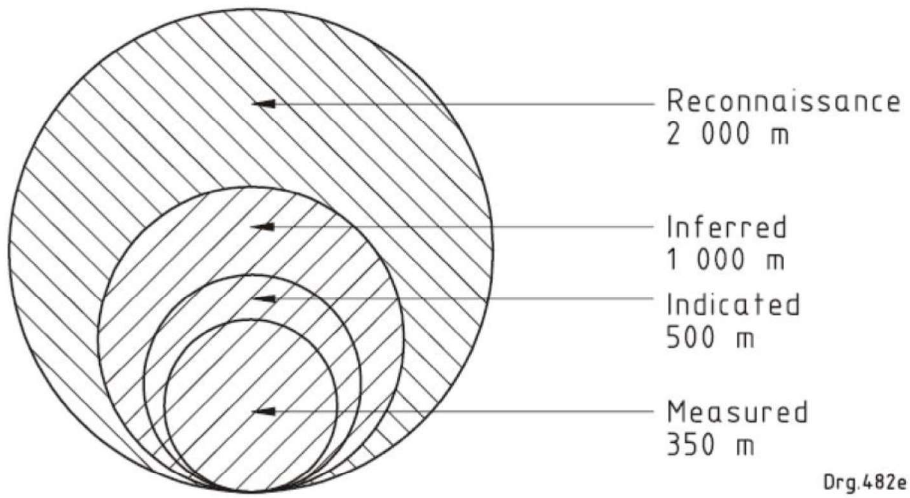


Figure 16: Coal Resources: minimum borehole spacing - schematic diagram to illustrate the minimum borehole spacing for each Coal Resource classification category for multiple seam deposit type Coal Resources (South African National Standard, 2004).

Deutsch, Leuangthong and Ortiz (2007) proposes the use of geometric criteria such as drill hole spacing supported by a valuation of uncertainty with geostatistical techniques. Bertoli, Paul, Casley and Dunn (2013) also presents geostatistical Drill Hole Spacing Analysis (‘DHSA’) as a technique to support classification of Coal Resources

Based on the geological complexity of the Witbank Coalfield, Magnus (2017) proposed alternative ways of classifying the Coal Resources taking into consideration the borehole distance spacing and on-site modus operandi per mining area; the proposed score card is tabulated in Figure 17.

Geological Occurrences	Description			Confidence factor	Weighting	Additional comments
Faulting	Unaffected by tectonic deformation			5	10%	Only known faulting, based on exploration drilling or geophysics, can be evaluated
	Affected by some extent of tectonic faulting, folds are open with long wavelengths and faults are uncommon			3		
	Severely affected by tectonic activity, folds are tight and over turned			1		
Weathering	Coal seams not affected by weathering			5	10%	The influence of weathering as a result of the limit of weathering or in the vicinity of faults/dykes need to be evaluated
	Coal seams mildly affected by weathering			3		
	Coal seams severely affected by weathering			1		
Intrusions	Unaffected by magmatic intrusions			5	10%	The influence of intrusions in terms of effect on coal quality and size of intrusions need to be considered
	Affected by some intrusions, coal in the vicinity of intrusions are less burnt and affected area is less than 1x the thickness of the intrusion			3		
	Severely affected by intrusions, coal in vicinity of intrusions are burnt and affected area is more than 1x the thickness of intrusion			1		
Floor undulations	Moderate floor undulations of less than 10º expected			5	5%	Floor rolls are common in the Witbank coalfield and causes difficult mining conditions, especially for underground workings
	Moderate floor undulations of less than 15º expected			3		
	Moderate floor undulations of more than 15º expected			1		
Geological variability	**Level of assurance**				**Weighting**	
Drill spacing providing geological confidence	Zone 1	Zone 2	Zone 3			As delineated in Figure 17 of this research report
	High: Drillhole spacing less than 100m	High: Drillhole spacing less than 200m	High: Drillhole spacing but less than 200m	5	30%	Please see proposed geological zones in Figure 17
	Moderate: Drillhole spacing greater than 100m, but less than 150m	Moderate: Drillhole spacing greater than 150m, but less than 200m	Moderate: Drillhole spacing greater than 200m, but less than 250m	3		
	Low: Drillhole spacing greater than 150m	Low: Drillhole spacing greater than 200m	Low: Drillhole spacing greater than 250m	1		
Quality of data	**Level of confidence**					
Assay data	High level of confidence, relevant and appropriate QAQC applied to all data			5	15%	
	Moderate level of confidence, QAQC applied, but not to satisfactory levels/standards			3		
	Low level of confidence due to historic data/labs or little or no QAQC applied			1		
Logging data	High level of confidence, relevant and appropriate QAQC applied to all data			5	20%	
	Moderate level of confidence, QAQC applied, but not to satisfactory levels/standards			3		
	Low level of confidence due to historic data/labs or little or no QAQC applied			1		
TOTAL					**100%**	

Figure 17:Coal Resource Classification, incorporating geological factors, geostatistical analysis as well as drill hole spacing analysis (Magnus, 2017)

2.2 Geostatistical estimation techniques

The knowledge and understanding of the different techniques used in the resource estimation process is imperative. Methods such as kriging, IDW and nearest neighbour estimation are the traditional geostatistical approaches used in Coal Resource estimation (Atalay & Tercan, 2017).

It is imperative that the accuracy of the estimation technique be evaluated so to assist with proper mine planning. The accuracy of an estimate depends on estimation technique used; the nature of mineralization, samples or drill hole spacing and their configuration; block sizes being estimated and proximity of these samples with respect to the blocks (Baafi & Kim, 1982).

2.2.1 Minex Growth Algorithm

Estimation techniques commonly used in the coal mining industry are IDW, Kriging and the MGA (Surpac Minex Group, 2005). The MGA is widely used by most South African coal mines and involves a two-stage process during the creation of the grid models. Stage one involves the creation of four mesh points around the known data as depicted in Figure 18 using a sexto-decimo sector search (Surpac Minex Group, 2005).

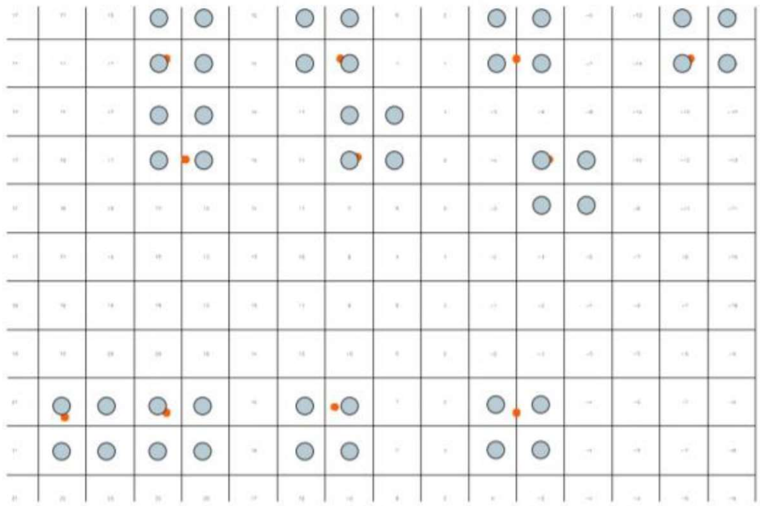


Figure 18: Stage 1 of the growth algorithm depicted the mesh points

The second phase uses the calculated average between a secant and tangent plane for each grid intersection to calculate mesh points and discard the known data as the mesh grows outwards filling in the missing mesh points as depicted in Figure 19 (Surpac Minex Group, 2005).

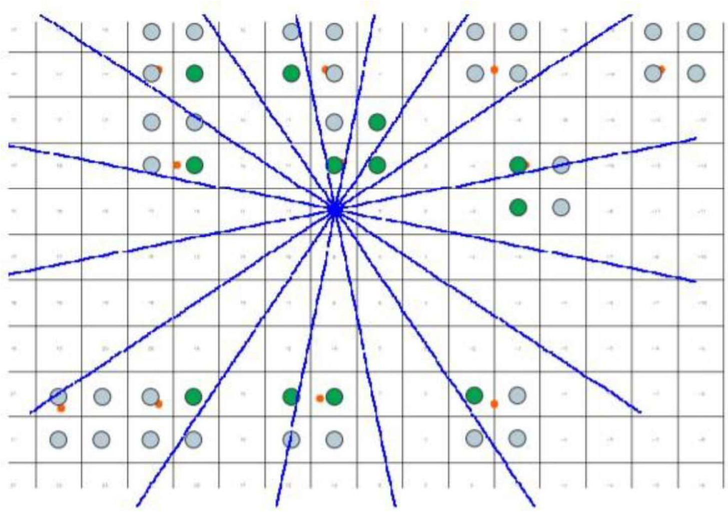


Figure 19: Generation of secant planes for point X during stage 2 is controlled by green nodes (assuming for clarity one point per sector)

2.2.2 Inverse distance weighting

IDW assumes that samples that are close to each other have more influence towards each other than those at a further distance (ESRI, 2021). To estimate an unknown value, IDW uses the values surrounding the unknown point and gives each a weight based on the distance from that point, these weights decrease with an increase in distance from the unknown point (Liu, et al., 2021).

Figure 20 illustrates an example of the weights assigned to points based on their locality from the point to be estimated where the centre of the circle is the point to be estimated.

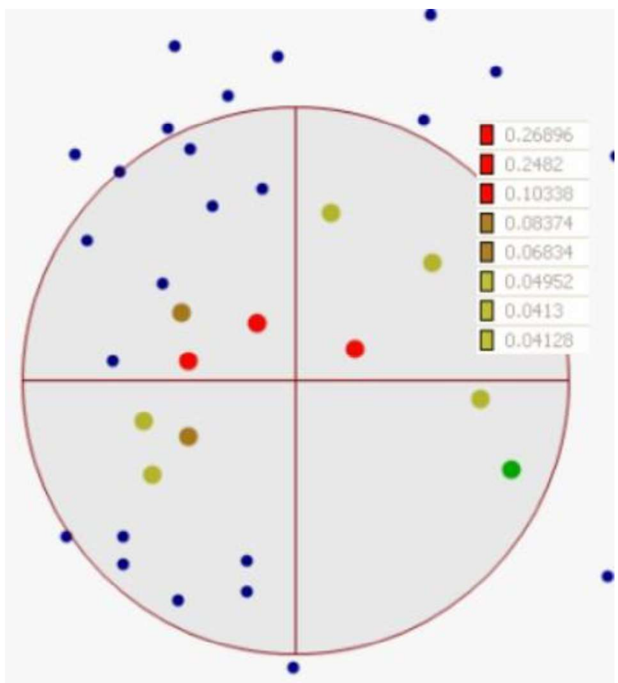


Figure 20: Neighbourhood illustration (ESRI, 2021)

Comparing the IDW and MGA the Surpac Minex Group (2005) mentions that the distance weighing is limited to the minimum and maximum between two points that are used to estimate and thus cannot produce estimates greater than those points used, as depicted in Figure 21, the growth algorithm can estimate values that are greater or less than the known data values. This gives the MGA an advantage over IDW as sometimes values to be estimated are greater or lesser than those of the neighbouring values but also a disadvantage as the MGA ends up smoothing the contours of estimation even where not necessary.

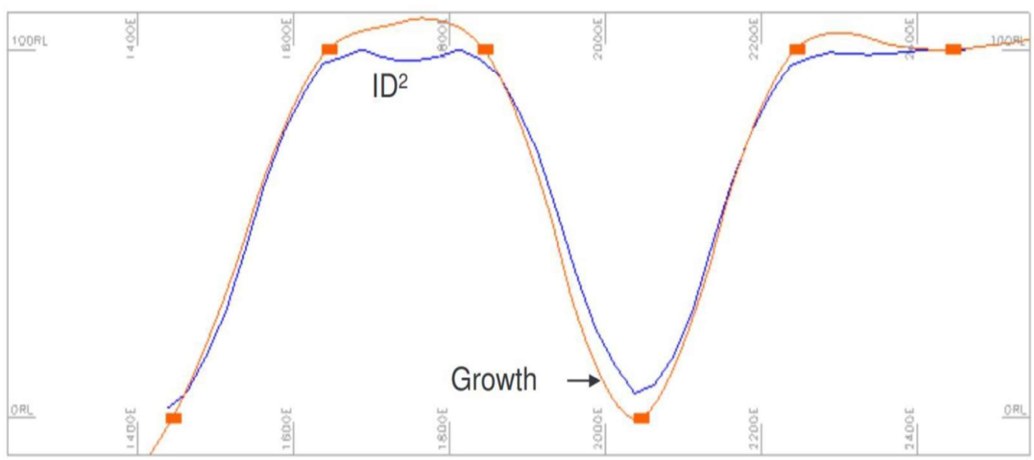


Figure 21: Inverse distance squared versus growth algorithm estimation (Surpac Minex Group, 2005)

2.2.3 Ordinary Kriging

The using of any Kriging method requires the construction of an experimental variogram to determine spatial dependence of data (Mesić Kiš , 2015). Equation 1 expresses the experimental variogram.

$$2\gamma^{(h)} = \frac{1}{N(h)} \times \sum_{n=1}^{N(h)} [z_n - z_{n+h}]_2 \qquad \textit{Equation 1}$$

where, *N*(*h*) refers to the number of data pairs at distance "*h*" (inside searching neighbourhood area), *Z*(n) a value at location n and Z(n+h) the value at location *n+h* (Mesić Kiš , 2015).

The possible variogram models to be considered by the resource modeller when fitting a model to the experimental variograms are shown in Figure 22.

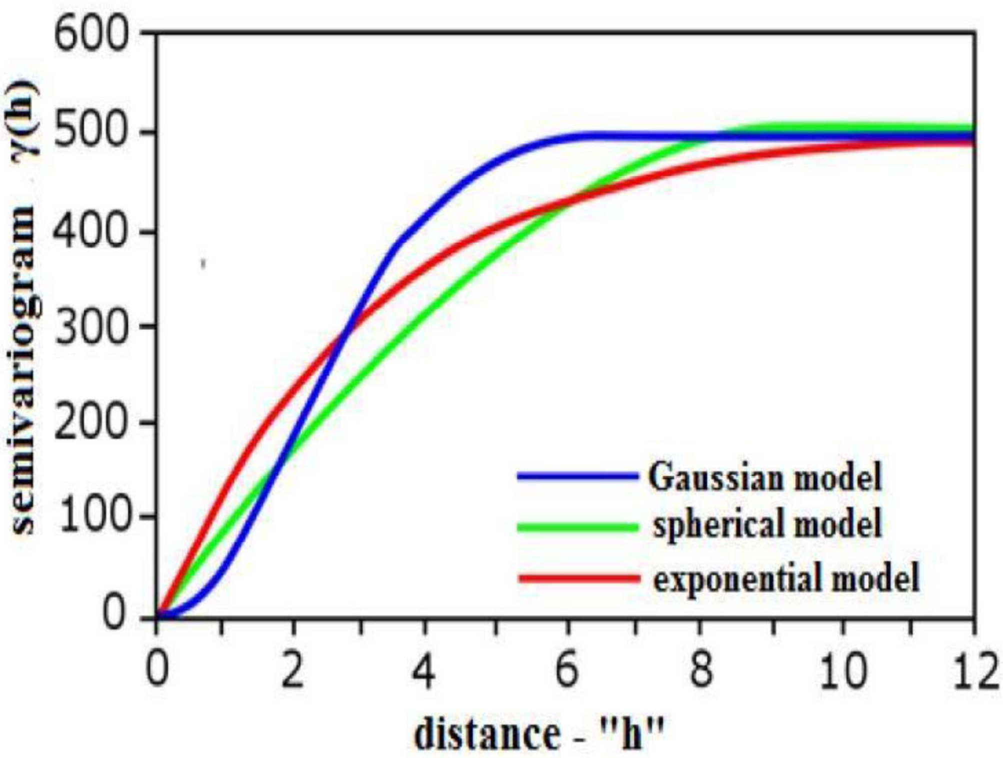


Figure 22: Theoretical experimental variogram models (Mesić Kiš , 2015)

Each variogram model is defined by a different mathematical equation as shown in Table 2.

Table 2: Equations for the Variogram models (Asim & Cheng Si, 2013)

Name of Model	Equations †
Spherical Model	$\gamma_s(h;a,b,c) = \begin{cases} a + (b-a)\left[1.5\frac{h}{c} - 0.5\left(\frac{h}{c}\right)^3\right] & if\, h \leq c \\ b & otherwise \end{cases}$
Exponential Model	$\gamma_e(h;a,b,c) = a + (b-a)\left\{1 - \exp\left(\frac{-h}{c}\right)\right\}$
Gaussian Model	$\gamma_g(h;a,b,c) = a + (b-a)\left\{1 - \exp\left(\frac{-h^2}{c^2}\right)\right\}$
Linear Plateau Model	$\gamma_l(h;a,b,c) = \begin{cases} a + (b-a)\frac{h}{c} & if\, h \leq c \\ b & otherwise \end{cases}$

As depicted in Figure 13, from the variogram models, the user can model the Nugget, Sill (variance), Range and Distance which are then used to estimate points where no value is present.

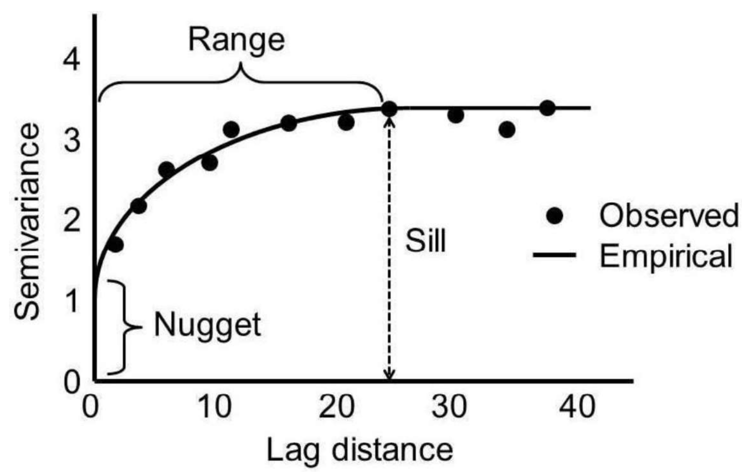


Figure 23: Variogram Parameters (Asim & Cheng Si, 2013)

With Variogram analysis completed, Kriging may be executed. The Minex software offers Ordinary Kriging (OK). Because of it being a "best linear unbiased estimator" (BLUE), OK has become the most commonly used

Kriging technique as it aims to minimise the variance of the errors, the estimates are weighted linear combinations of available data and also tries to have the mean error equal to zero (Mesić Kiš , 2015).

Ordinary Kriging (OK) is successful in applying spatial correlations between values at different locations and cross-correlations between different variables at the same location and is thus widely used in establishing coal models. Srivastava (2013) describes OK as an estimation procedure that uses weighted averages in which the weights sum to one. OK allows the user to control kriging weights through their choice of a variogram model. User defined nugget effect, sill and ranges are used in the kriging calculations to minimize the estimation variance.

Cornah, Vann and Driver (2013) further compares CS, the discrete Gaussian Model (DGM) and the global estimation variance (GEV) as techniques to quantify the impact of drill spacing on resource confidence for a coal seam. These approaches in their study resulted in broadly similar characterization of uncertainty in the percent yield as shown in Figure 24.

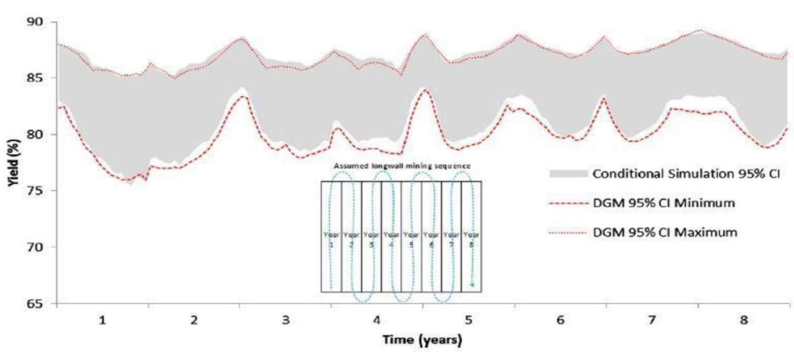


Figure 24: Comparison of DGM and conditional simulation 95% confidence intervals on Yield over an 8-year mining sequence on a block-by-block basis (Cornah, et al., 2013).

Cornah et al. (2013) explain CS as the generation of realisations of the deposit which replicate the global declustered histogram and variogram at the scale of the sample data and these results can then be ‘averaged’ to generate block-scale results. Moreover, the simulations honour sample data locations and from the full set of realizations, local probability distributions can be created, which can be used in the calculation of local (or global) confidence intervals (Cornah, et al., 2013).

Kannenberg et al (1987) compares conditional simulation (CS) to kriging for the prediction of seam thickness distribution against a pre-determined cut-off thickness as depicted in Figure 25. Their study showed that kriging tends to underestimate the proportions beyond cut-off due its smoothing nature whereas conditional simulation produced results which comply better with said objectives and were more realistic thus could assist mine planning appropriately.

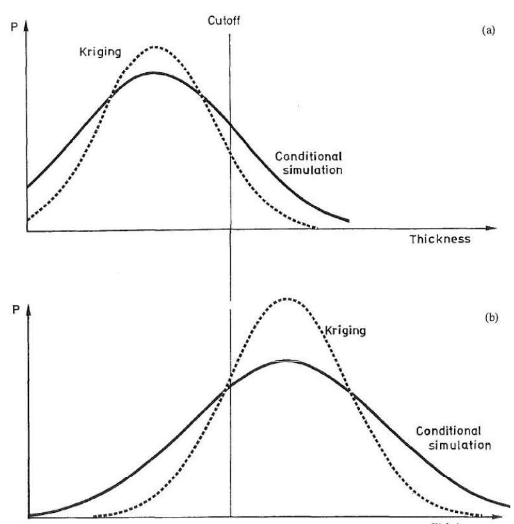


Figure 25: Over- versus under-estimation of seam thicknesses; kriging versus conditional simulation (Kannenberg, et al., 1987)

When exploring which model to adopt, the modeler should be well acquainted with their objective as each model takes precedence over the other based on it. Where resource estimation (coal tonnages and quality) is the main objective, OK is the preferred method, however in instances where blending strategies should be put in place and be controlled by short-scale variable changes, CS is the better approach to establishing a model (Srivastava, 2013).

2.2.4 Discussion

A room for improvement is observed in the available literature as far as the MGA is concerned, currently only one publication from the Surpac group exists explaining how the MGA works but the mathematics behind the technique is not discussed in detail.

The IDW and OK has been thoroughly researched and documented, based on available publications, the IDW and OK has advantage of the MGA as the methods and results can be explained mathematically.

3 KPSS Geology data

This section looks at the spatial distribution of the boreholes drilled at KPSS, it further looks at possible relationships which may exist between the coal quality variables Ash and CV while outlining anomalies that can be derived from this relationship. Detailed borehole log are discussed to investigate other exploratory data analysis techniques which can also reveal anomalous data.

A brief explanation on the local Geology and stratigraphy of KPSS has been discussed in Section 1.3 of the research report.

3.1 Exploratory Data Analysis

There has been extensive exploration for the Klipspruit South Pit of the Klipspruit Colliery. Over the past decade 74 boreholes have been drilled in the Klipspruit South eastern pit area to determine the occurrence and behaviour of the coal seams of interest. Figure 26 indicates the locality of the boreholes drilled in the study area.

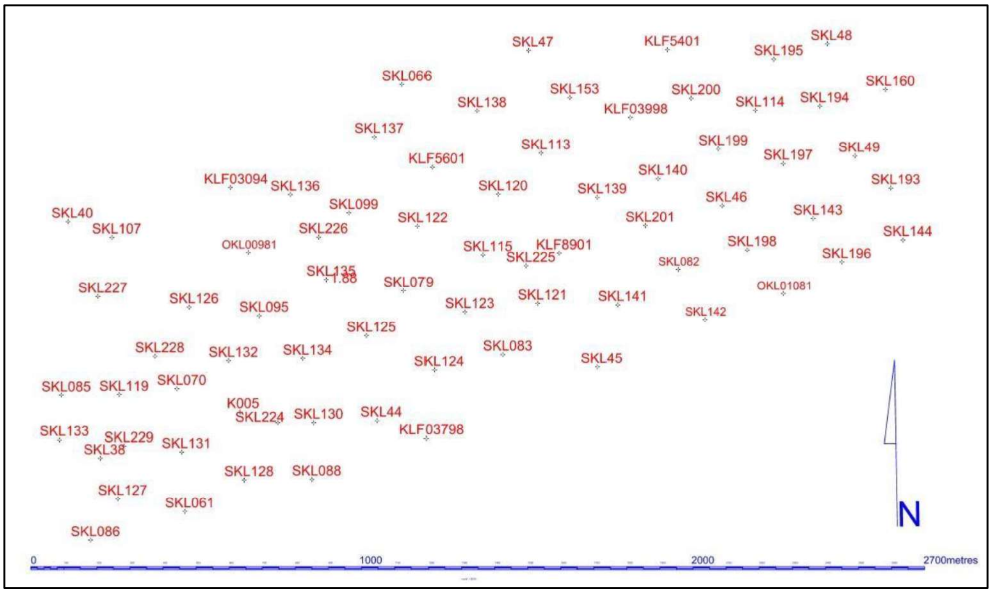


Figure 26: Locality of the boreholes drilled at KPSS eastern pit.

As depicted in Figure 27, the average distance between the boreholes is about 100 m, and is thus classified as a Measured Coal Resource as per the SANS standards.

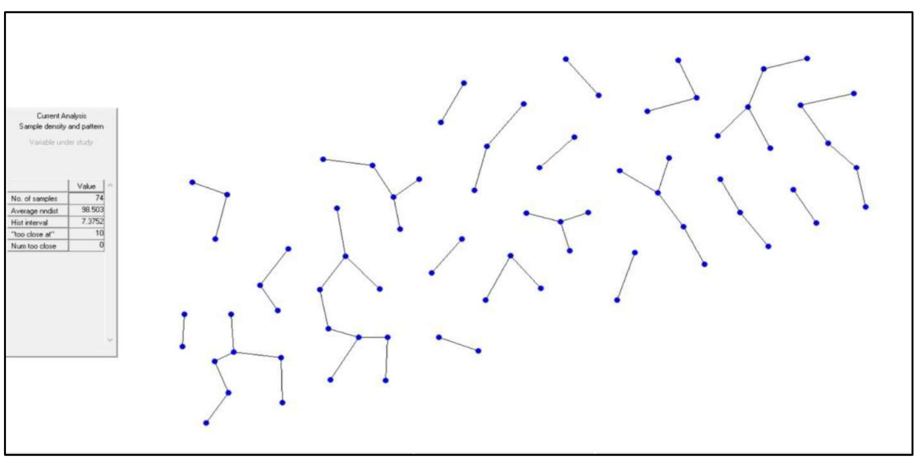


Figure 27: Nearest neighbour plot of the KPSS eastern pit boreholes (Generated using Geostokos Software)

From the 74 boreholes drilled, three boreholes were not sampled thus these boreholes only have seam thickness in the general lithology logs but no quality variables. Figure 28 highlights the three borehole localities of the unsampled boreholes.

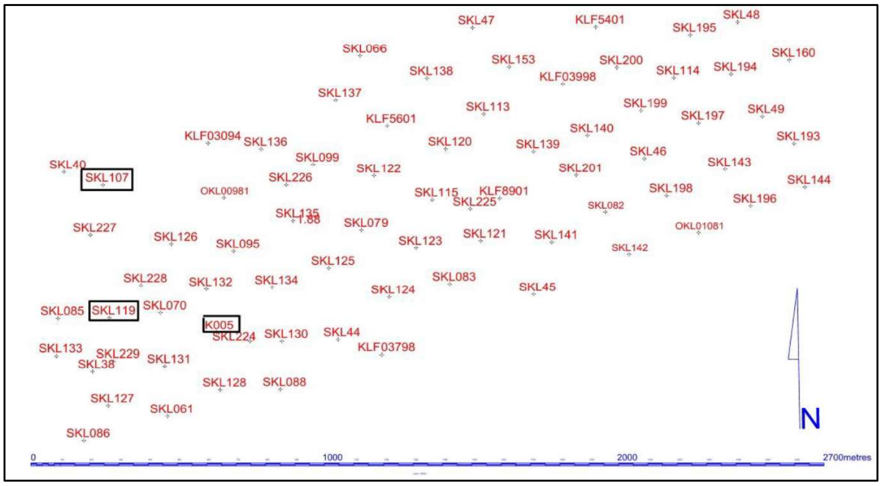


Figure 28: Locality of boreholes not sampled

Where core is highly weathered, core cannot be recovered as due to the weathered coal being lost in the process of drilling, it is washed away by the water. Historically, the Number 5 Seam was not a coal seam of economic interests, thus it also happened that this seam was not sampled during logging to save costs. Table 3 indicates the coordinates, seam thickness and reason for the above-mentioned boreholes to not be sampled.

Table 3: Boreholes not sampled

Borehole ID	X	Y	Z	Seam thickness (m)	Reason for not sampling
SKL107	2716.22	-2883264	1587.04	1.18	Highly weathered (no core recovered)
SKL119	2724.79	-2883559	1593.5	0.86	Highly weathered (no core recovered)
K005	2950.89	-2883596.3	1593.5	1.67	No reason stipulated in the Database

Scatter and probability plots show the relationship between the coal variables to each other and the behaviour of the population of samples. Generally, the Ash and Calorific value (CV) relationship is checked to assess reliability and representativity of the data. Figure 29 shows the relationship between Ash and CV of the number 5 Seam samples taken from the 71 boreholes which had quality sample values.

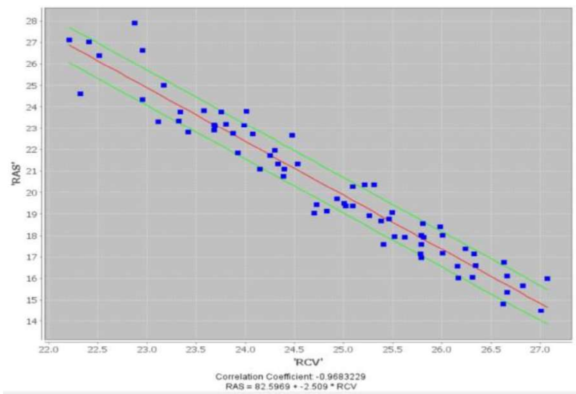


Figure 29: Relationship between Ash (RAS) and CV (RCV) of the Number 5 Seam at KPSS

From Figure 29, a strong inversely proportional relationship between the Ash and CV is observed which is what is expected for the Witbank Coalfields seams.

To investigate the behaviour of the population of samples a probability plot using CV of these samples was drawn, this plot is represented in Figure 30

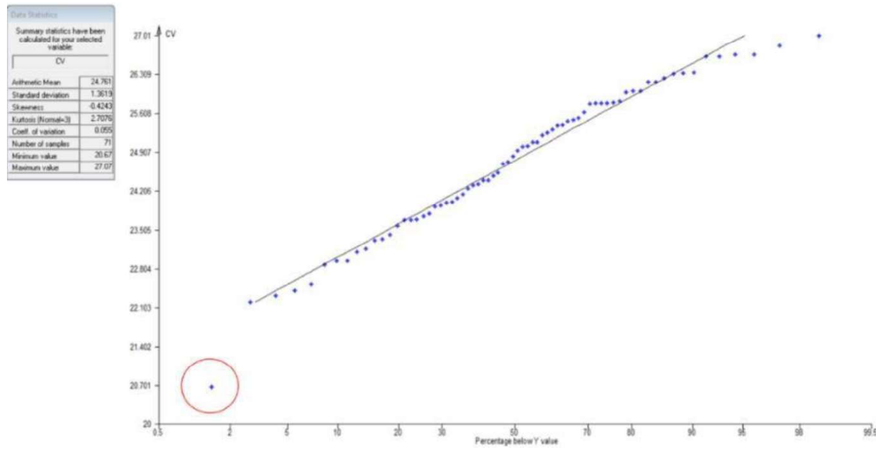


Figure 30: CV Probability plot from the KPSS Number 5 Seam samples (Generated using Geostokos software)

Figure 30 shows the coal seam is homogenous but have an anomalous sample or area that may be affected by other factors which results in the outlier observed.

Figure 31 shows the location of sample where the CV shows to be different from the rest of the populations using and indicator plot.

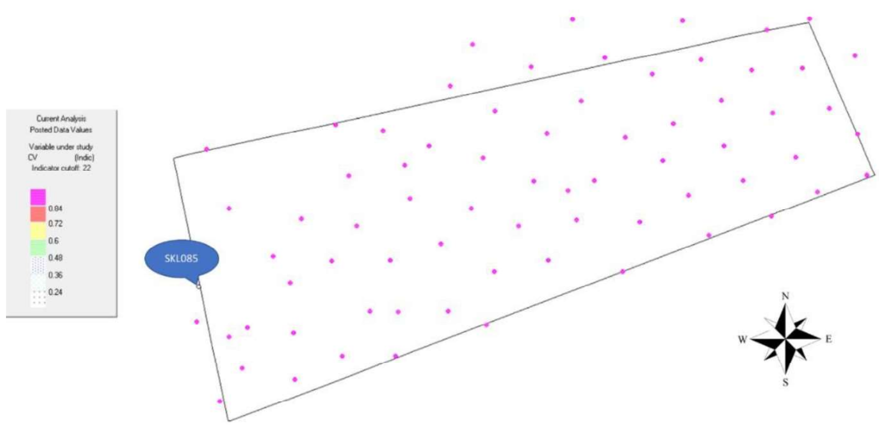


Figure 31: Indicator plot showing the location of SKL085 in relation to other samples (Generated using Geostokos software)

The sample that show to be an outlier or of a different population was observed that the high Ash and low CV qualities are due to sampling errors. The log and samples taken from this borehole is depicted in Figure 32.

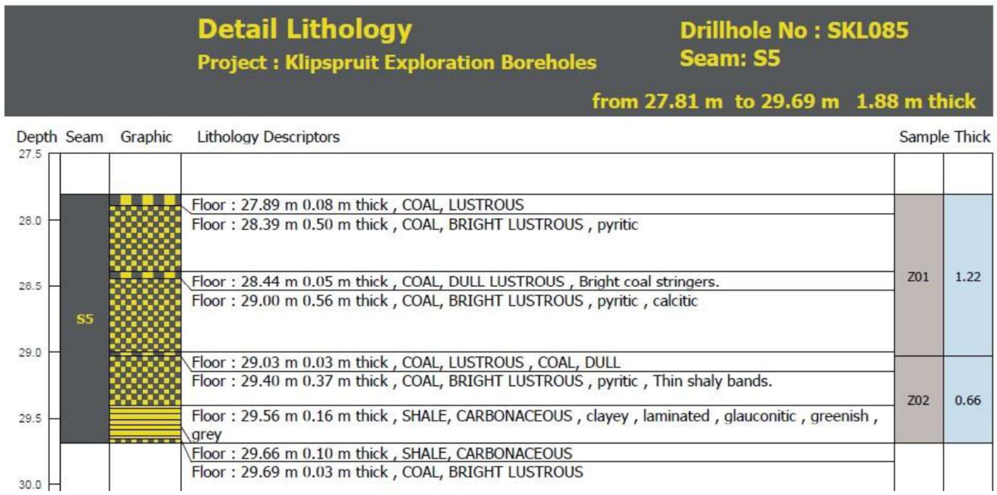


Figure 32: Detailed borehole log for SKL085 Number 5 Seam

From the borehole log for SKL085 it has been observed that the seam thickness and sampling was erroneous. The coal seam should be from 27.81m to 29.40m thus seam thickness should be 1.59m. The reported seam thickness introduces 0.29m of contamination thus increasing the Ash and lowers the CV of the borehole.

Figure 33 indicates the CV probability plot excluding SLK085.

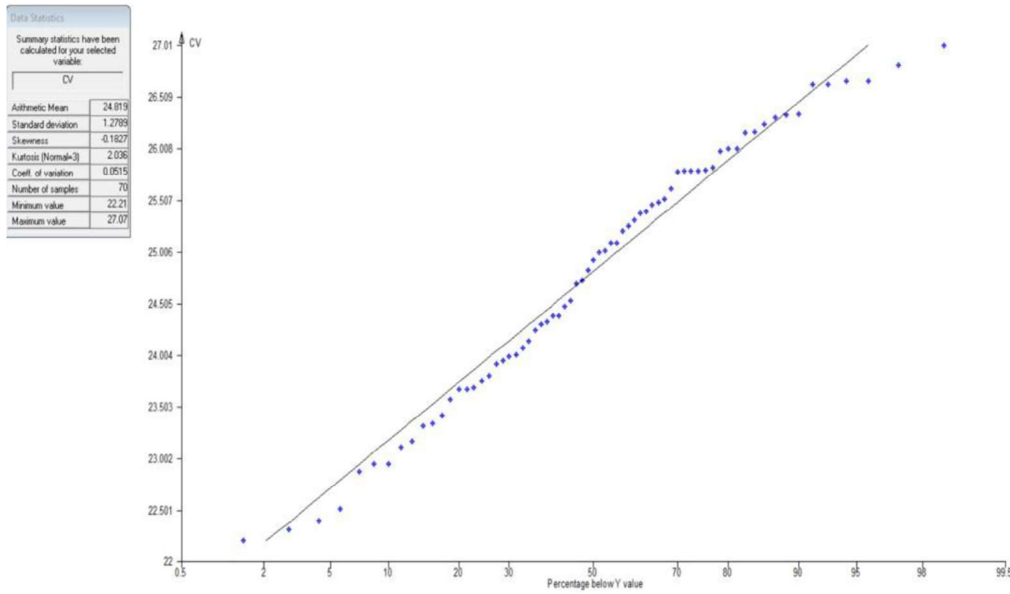


Figure 33: Number 5 Seam Raw CV Probability plot (Generated using Geostokos Software)

The strong correlation between CV and Ash observed in Figure 33 shows that there is no need to plot an Ash probability plot and variogram.

To establish what the behaviour of the coal seam as far as seam thickness is concerned, a cumulative distribution plot represented in Figure 34 was created. All 74 boreholes drilled have a seam thickness value, however only 73 were used as SKL085 has been discarded due to it being erroneously sampled.

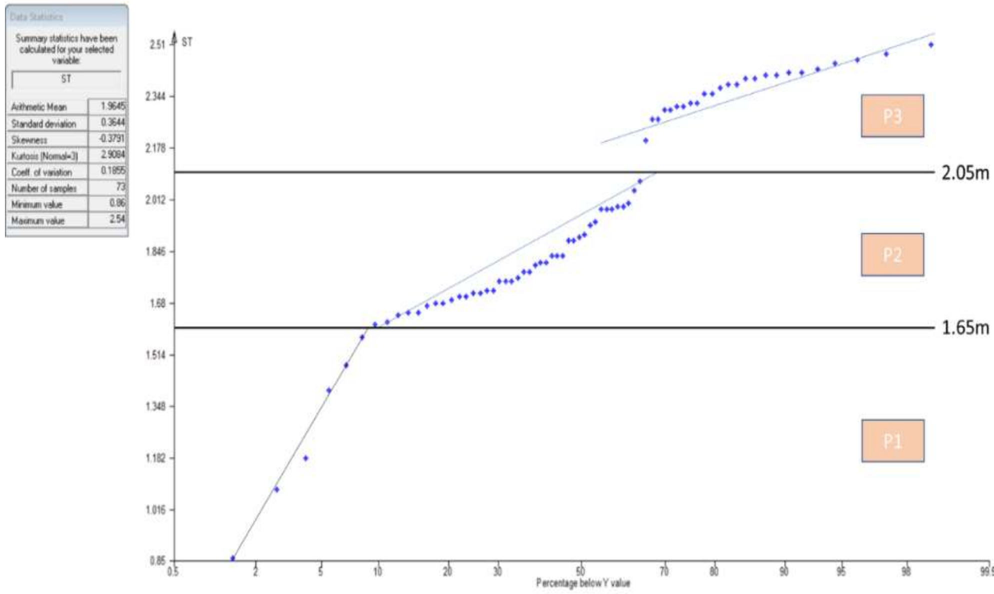


Figure 34: KPSS Number 5 Seam thickness probability plot (Generated using Geostokos Software)

Figure 34 shows the presence of more than one ST population from which the data has been derived, these populations show that the samples have been affected by some geological activity and each represent a different domain; these Domains are named P1, P2 and P3 in Figure 34.

The location of the data hosted in each of the domains have been depicted in Figure 35 where the location of each domain is illustrated in the diagram. From the location of SKL107 and SKL119 which was not sampled as core was not recovered due to extensive weathering, it is evident the P1 Domain seam thickness has been affected by weathering.

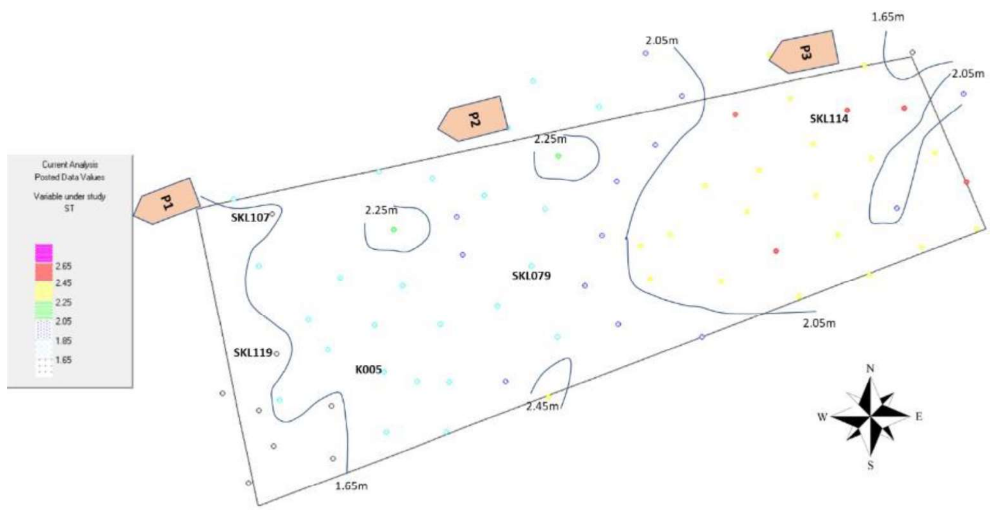


Figure 35: Borehole seam thickness and locality of boreholes not sampled also indicating the different Domains (P1, P2. P3) in the study area

Figure 36 shows the detailed log for SKL079, located within the P2 domain; this borehole is assumed to be representative of the boreholes within this domain and indicates that weathering has not affected the Number 5 Seam coal in this domain.

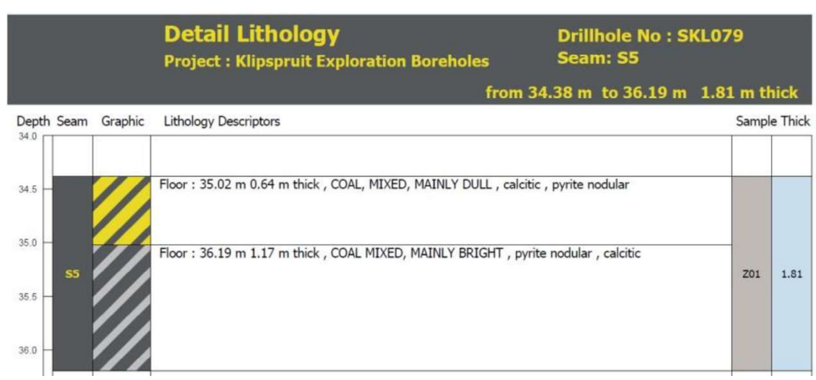


Figure 36: Detailed log for SKL079 Number 5 Seam coal.

Figure 37 depicts the detailed log for SKL114 located within the P3 seam thickness domain.

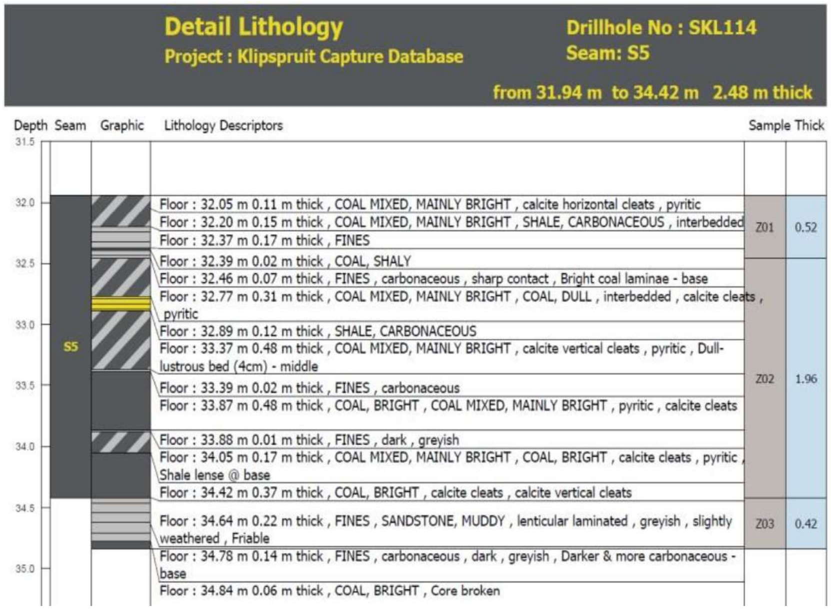


Figure 37: : Detailed log of SKL114 Number 5 Seam coal

Comparing Figure 36 and Figure 37 it was observed that the coal within the P3 domain is composed of an upper portion of about 0.5 m bright coal intercalated with shale which indicates deep level water conditions during deposition and formation of the coal seam.

In the P2 domain this bright coal intercalated with shale is however not evident in the upper portion of the coal seam; this is indicative of erosional activities that affected the P2 domain. The above-mentioned factors indicate that the data is not of a normal distribution.

3.1.2 Discussion

Exploratory data analyses gives insight to the distribution of the data populations. Commonly reviewed in coal data is the CV and Ash relationship however there are other techniques such as ST analysis that can be used to reveal anomalous data and domaining thereof.

Whichever resource estimation technique a resource modelers chooses, it is imperative to consider all domains for the estimations for more accurate results.

4 Resource estimation in Minex

Resource modelling in the coal mining industry is mostly done through Minex, a coal modelling software. Minex gives the user three main estimation methods that may be used for gridding during resource modelling and estimation i.e. MGA, IDW and OK.

This research project explores these methods through investigating what each entail, using the same parameters, these methods will be used to grid the coal variables such as ST, CV and Ash and their differences will be documented.

4.1 Variables estimations: Minex growth algorithm

ST plays a major role in determining the mineability of a coal seam. Figure 38 depicts the variations in ST of the Number 5 Seam in the study area. A general thinning of the seam is observed from Northeast to Southwest. The thinning of the seam indicates that non-stationarity of the coal seam thickness. This further supports the presence of the three populations of data as depicted in Figure 35, these populations should be considered for any estimation technique to be selected.

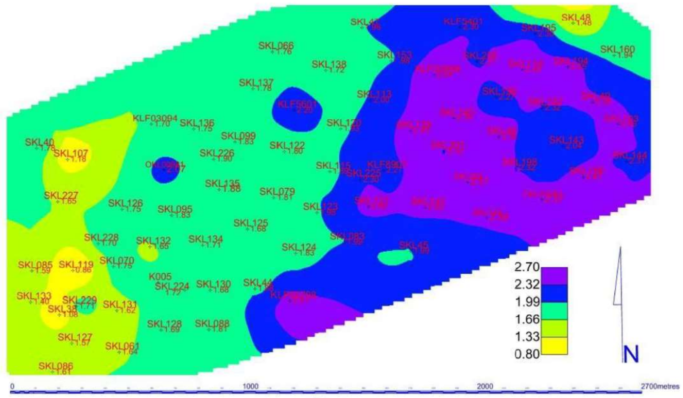


Figure 38: Number 5 Seam ST plot using the MGA

Figure 39 indicates the CV as modelled in the project area, this plot indicates a CV that increases with a decrease in seam thickness in this area. CV values observed increasing from Northeast to Southwest of the study area with some localised areas on the high CV areas due to seam thickness and those areas not affected by any weathering or erosion.

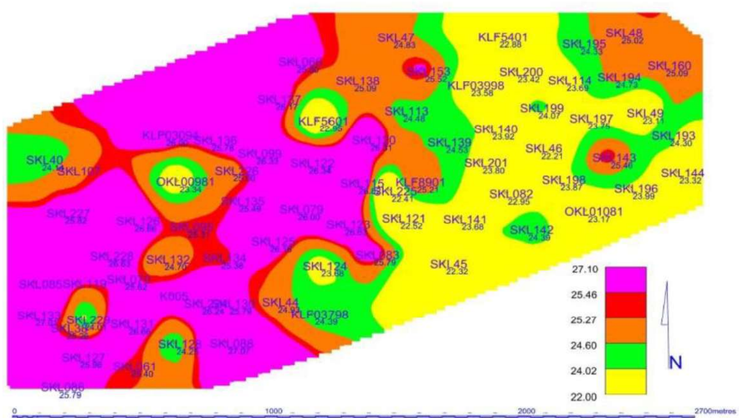


Figure 39: Number 5 Seam CV plot using the MGA

A relationship between CV and Ash has been established in Figure 29, this relationship is observed also when analysing the Number 5 Seam CV distribution depicted in Figure 40 and the Ash distribution depicted in Figure 41, these figures highlights the inverse relationship between Ash and CV spatially.

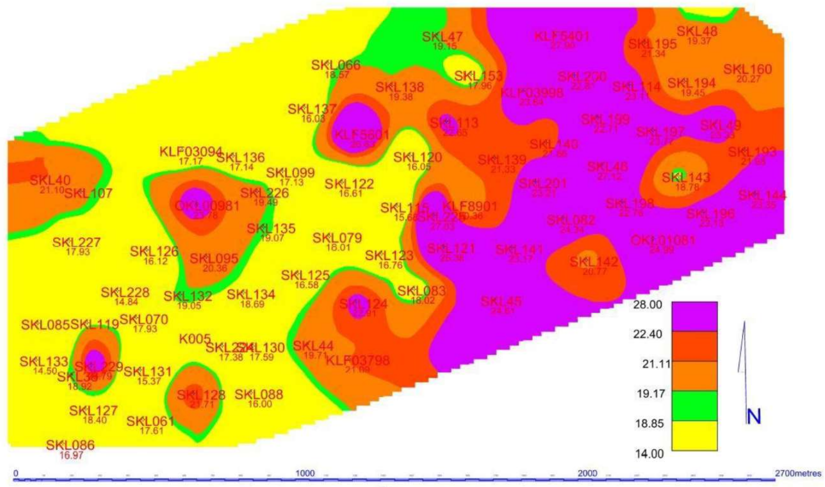


Figure 40: Number 5 Seam Ash plot using the MGA

4.2 Variables estimation: Inverse Distance

Figure 41 through to Figure 43 shows the ST, CV and Ash plots using the IDW estimation methodology.

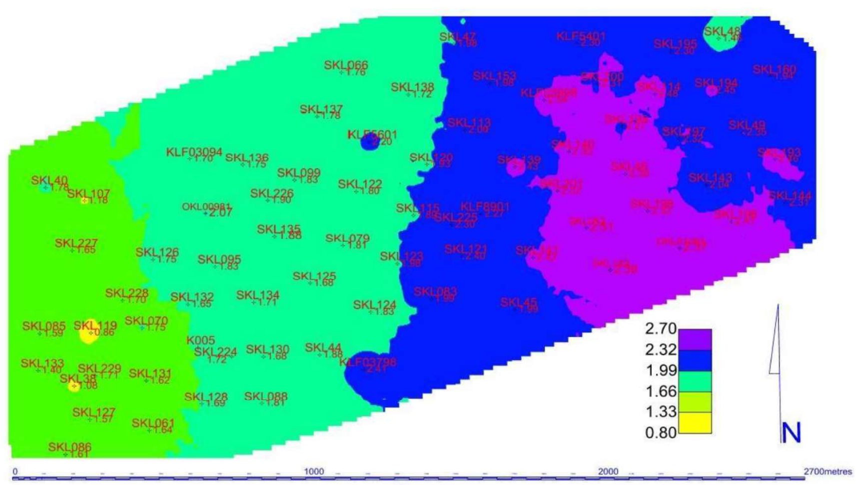


Figure 41: ST plot for the Number 5 Seam using IDW

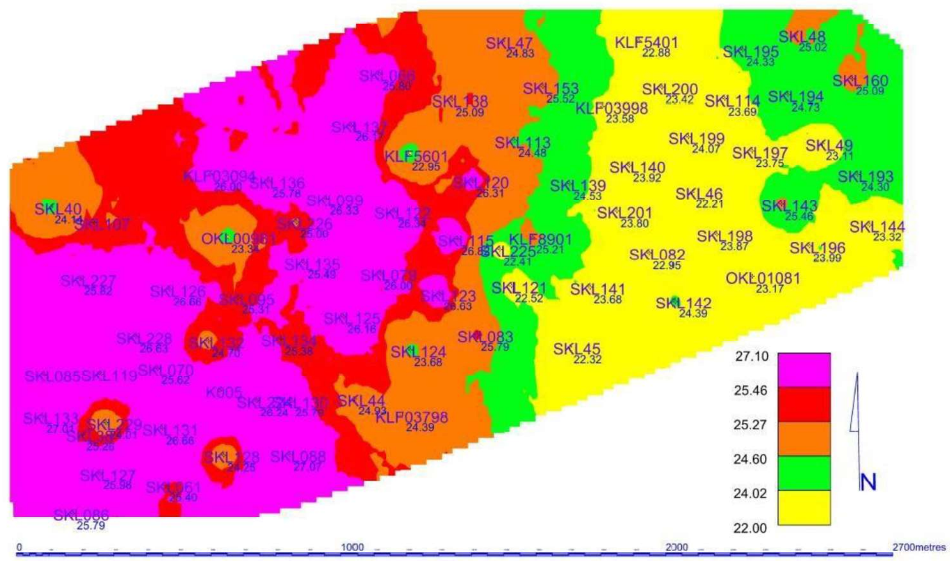


Figure 42: CV plot of the Number 5 Seam using IDW

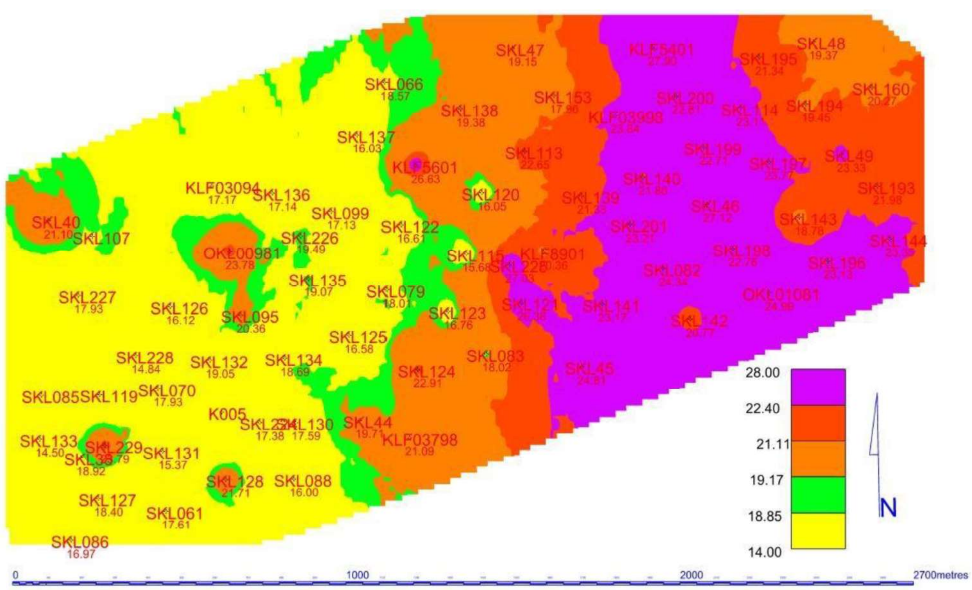


Figure 43: Ash plot of the Number 5 Seam using IDW

A change is observed between the MGA and the IDW estimates however, the inversely proportional relationship of CV and Ash is still observed spatially. The ability of the MGA technique to estimate values that are lesser or higher than neighbouring values as shown in Chapter 2, Figure 21, is evident in the smoothness observed in the MGA estimates as compared to the IDW technique. This difference may result in the MGA either over estimating or underestimating some values in areas where data does not exist.

4.3 Variables estimation: Ordinary Kriging

Ordinary Kriging (OK) is used in Minex for the creation of grids this method includes variography to establish the Nugget, Sill and Range of influence of the data set to be used for gridding. Most professionals in the coal mining industry have not explored this option during modelling or resource and reserves estimation. This method requires more work and understanding of geostatistics by the user.

The limits in Minex for the fitting of a variogram model, to the data during variography introduces a room for error. Figure 44 Shows the Gaussian model which was fitted to the data in the principal direction, a spherical variogram model could have been fitted to the model, however this would be better done by hand rather than on the software as the software limits the moving of the nodes to fit in a model.

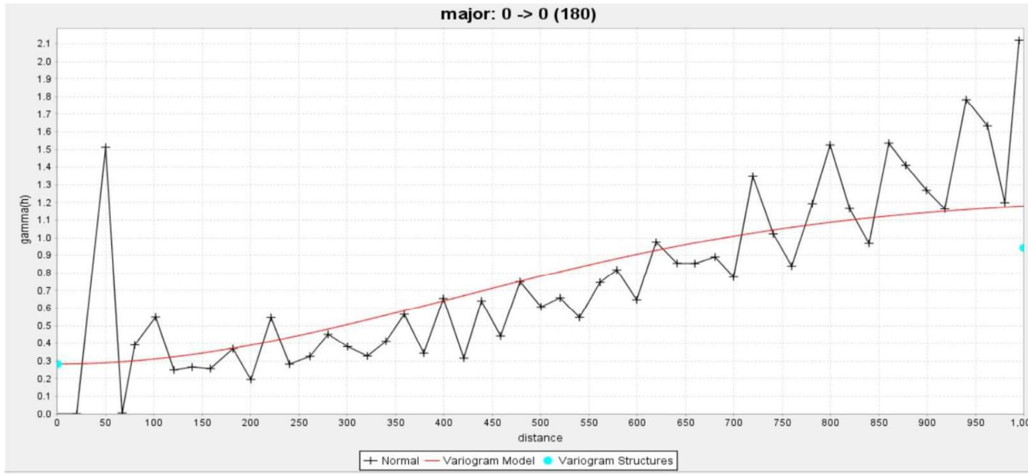


Figure 44: ST Gaussian variogram model in the principal direction

Table 4 Indicates the variogram model parameters as extracted from Figure 44, this data was then used to create the grids for the estimations of the ST using the OK technique. The Sill, Nugget and Range observed in Table 4 are high, these can be reduced with more flexibility afforded to the user in the Minex software, and will lead to different estimations as achieved in the research project.

Table 4: Variogram model parameters for the Number 5 Seam ST

Sill	0.943
Nugget	0.283
Range	1000m
Anisotropy Factors	
Major/Semi major	1
Major/minor	1

Figure 45 shows the resultant seam thickness plot as derived from Minex using the variogram parameters shown in Table 4.

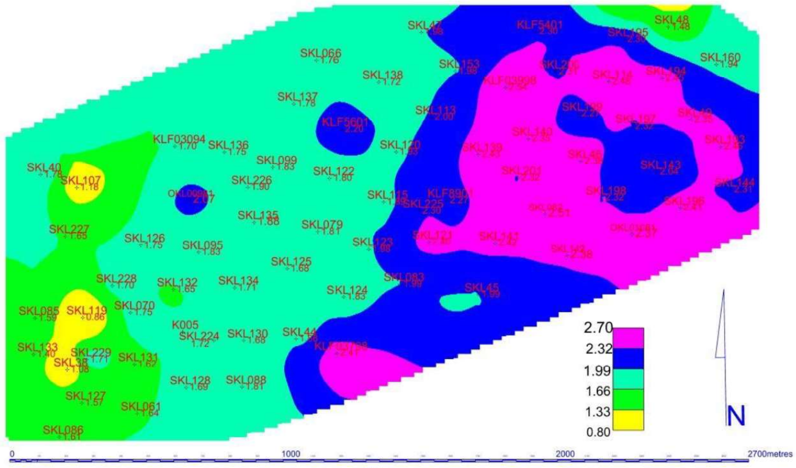


Figure 45: Number 5 Seam ST plot using OK

It has been established from Figure 33, the CV probability plot, that the Ash and CV data appears normal and has not been affected by geological activity. From the 74 boreholes in the project area, 70 boreholes can be used for the variogram modelling. The boreholes omitted are SKL085 as it was erroneously sampled and SKL119, SKL107 and K005 due to having no samples taken from these holes.

As with ST, a Gaussian model, though appearing not to be best fit, was fitted to the CV data, this is illustrated in Figure 46.

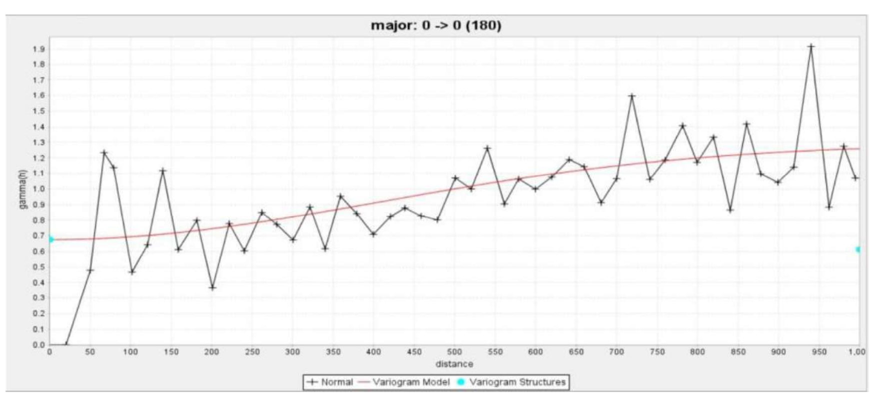


Figure 46: Gaussian variogram model in the principal direction for CV

Table 5 shows the variogram parameters as extracted from Figure 46

Table 5 : Variogram model parameters for the Number 5 Seam Raw CV

Sill	0.614
Nugget	0.676
Range	1000m
Anisotropy Factors	
Major/Semi major	1
Major/minor	1

Though a strong correlation exists between Ash and CV, Figure 47 depicts the Gaussian variogram model for the Ash

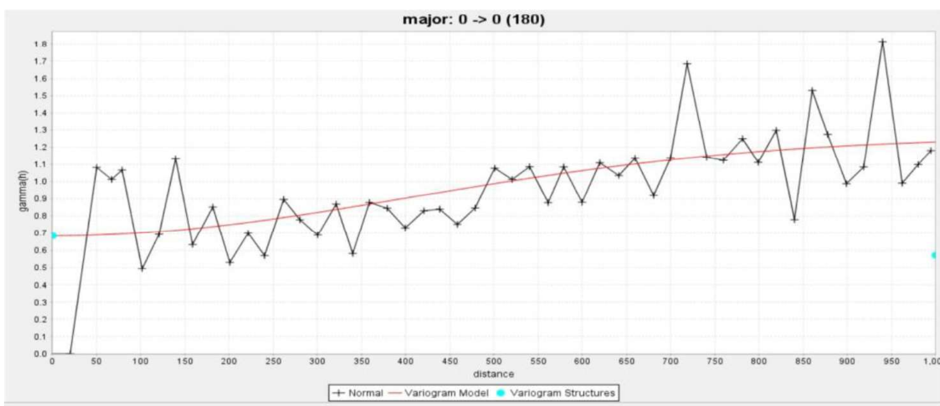


Figure 47: Gaussian variogram model in the principal direction for Ash

Table 6 shows the variogram model parameters as extracted from Figure 47

Table 6: Variogram model parameters for the Number 5 Seam Ash

Sill	0.614
Nugget	0.676
Range	1000m
Anisotropy Factors	
Major/Semi major	1
Major/minor	1

The semi-variogram models established in Figure 46 and Figure 47 were used in Minex to grid the raw CV and Ash, the results thereof are depicted in Figure 48 and Figure 49 respectively.

As was observed with the CV and Ash plots for the MGA and of IDW estimations, the correlation between CV and Ash as shown in Figure 29 is again spatially reproduced in Figures 48 and 49 as in sections 4.1 and 4.2.

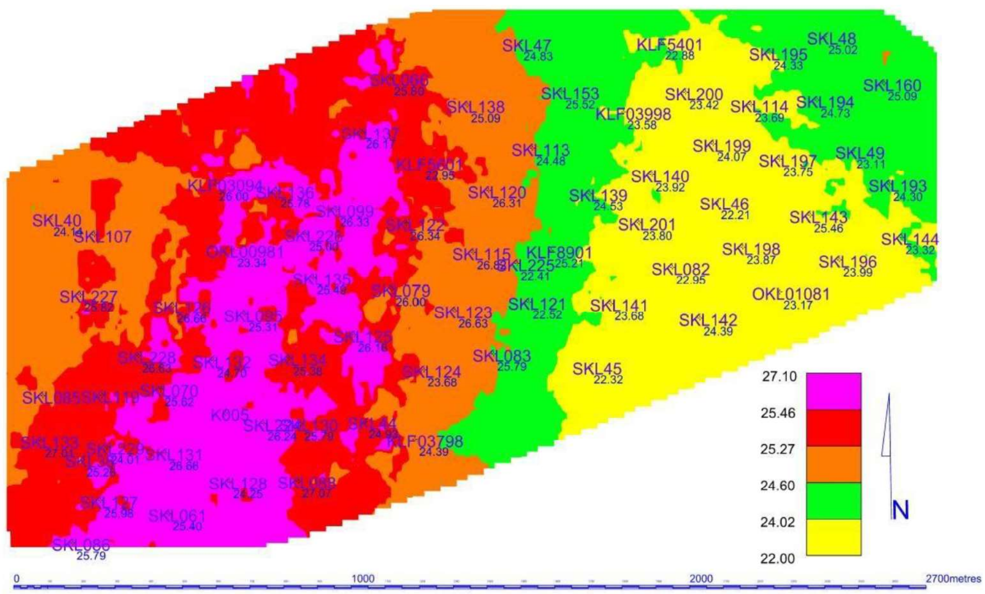


Figure 48: CV plot of the Number 5 Seam using OK

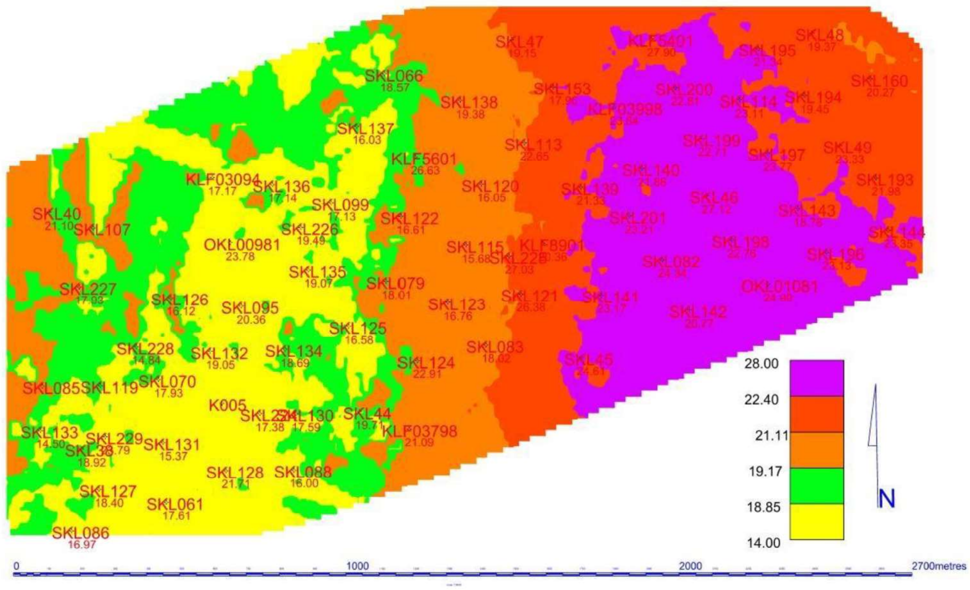


Figure 49: Ash plot of the Number 5 Seam using OK

4.4 Discussion

From the plots depicted in Figure 38 to 40 for the MGA, Figure 41 to 43 for IDW and Figures 45, 48 and 49 for OK it has been observed that all three methods used produce different results, depending on which estimation method is selected for estimating the variables. These representations are used to guide the planning and the mining team on which areas are expected to be economically extractable. It is thus imperative that the most accurate estimation methodology is used to report the Coal Resources.

As shown in Figure 34 and Figure 35, at KPSS three spatial populations for the Number 5 Seam thickness has been identified in the study area. The seam gets thinner from the Northeast moving to in the South-westerly direction. As per geological borehole logs, the data sets define a population which is a full seam (P3 Domain), a population where the upper portion of the Number 5 Seam has been eroded away (P2 Domain) and a population where the limit of weathering has extended into the Number 5 seam (P1 Domain).

Studies are ongoing in conjunction with the metallurgy department at KPS on how the plant can be set up to accommodate weathered coal. It is however imperative that the spatial extent of the P1 Domain one be spatially delineated. Further that this knowledge and understanding is communicated to management to ensure that P1 is given suitable thought until studies of plant processing adaption have been conducted. Weathered coal typically produces black water during processing at the plant; this increases viscosity of the recycled water which is fed back to the plant and gets mixed with the magnetite which subsequently affects density control and plant instability which ultimately results in plant inefficiency and production of off-spec products.

No weathering of coal has been observed in the P2 Domain, based on the coal seam estimation plots done of all three methods, the coal in this domain appears to be of very good quality and may be further investigated for processing.

The P3 Domain is composed of a thicker seam and is of lower quality compared to the P1 and P2 Domains, a need arises to explore the opportunities that may be present to optimize the extraction of the coal in this domain.

5 Establishing the optimal coal extraction method

Different extraction methods exist where the coal seam can be either mined as composite (mining the whole seam as one) or a selective mining approach where the seam is extracted in different horizons. As to which extraction method to be used, it is guided by the geological information obtained from the geological model and the factors used during the conversion of the Coal Resources to Coal Reserves. Factors to consider in the conversion are the mineability of the Resource, the environmental impact during extraction and the qualities of the coal, amongst other factors as defined by the SAMREC code.

This chapter explores the different extraction techniques in a geological modelling perspective using Geostatistics. The P3 Domain will be used for the investigation of the estimations achieved from the MGA, IDW and OK to establish which method produces results with the least variance.

5.2 Number 5 Seam Exploratory data analysis

Seam thickness plays a major role during Coal Resources and Reserve estimation and classification when determining which areas will be economically extractable and which areas will not.

Figure 50, though correlation is not perfect, supports the analogy that from the P3 domain going to the P2 domain (see Figure 35) the coal gets thinner and the quality (CV) of the seam also increases which is due to the erosion of the upper portion in P3 which is of bad quality. Further observed from Figure 50 is evidence of the existence of the three different populations of data.

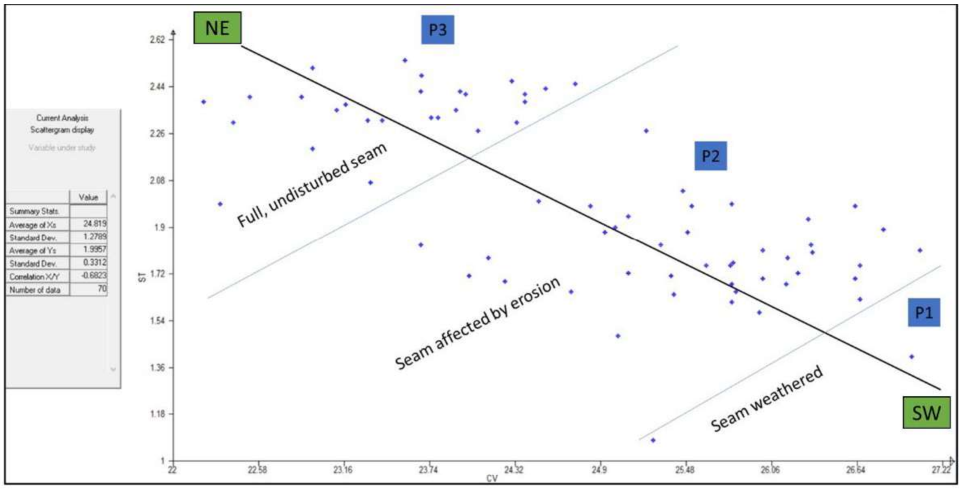


Figure 50: Seam thickness (m) versus CV (MJ/kg)

The thickest seam, which also shows to be of the lowest quality is hosted in the P3 Domain. This research study aims to identify the optimum extraction of the Number 5 seam in the P3 Domain using the estimation methods in Minex.

The P3 domain is composed of coal with a seam thickness greater than 2 m thus based on the mine available machinery, the possibility of selective mining can be explored. The P3 Domain is represented by 25 boreholes as depicted in Figure 51.

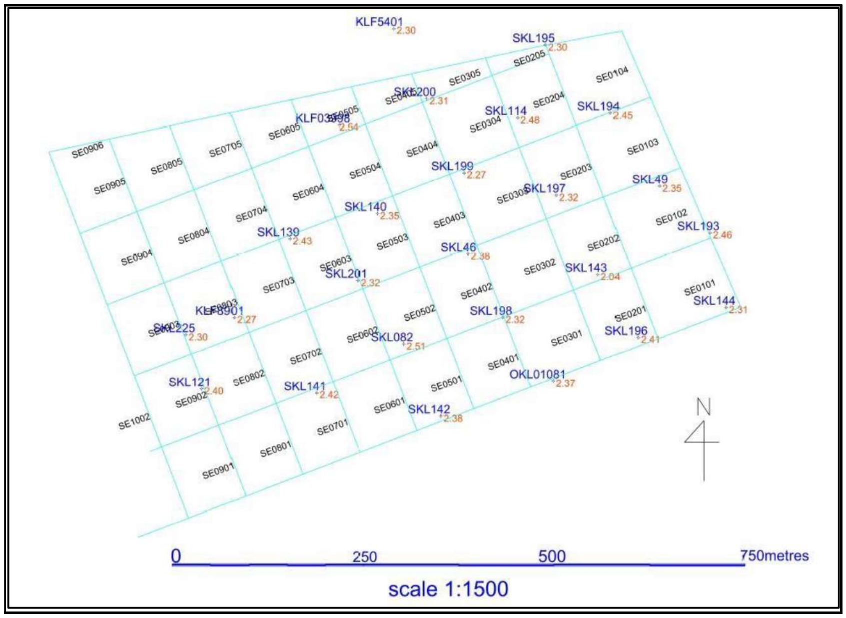


Figure 51: P3 Domain Boreholes and Number 5 Seam thickness of each hole

As observed in Figure 51, each borehole has a different seam thickness (red labels) ranging from 2.04 to 2.54m. These boreholes will be used for the gridding using the estimation techniques in Minex to explore the possibility of selective mining in this area to improve the Number 5 Seam coal extraction.

5.3 P3 Domain Number 5 Seam coal variables estimation

Figure 52 indicates boreholes where seam thickness and raw CV will be estimated, these borehole locations were strategically selected based on the number of samples that have been taken from each borehole. The seam thickness and CV for these boreholes will be estimated using the MGA, IDW and OK options in the Minex software, the results thereof will be compared to the known values of ST and CV at these locations. The point estimation method with the least difference to the known values will be identified as the estimation methodology to be applied for P3 domain estimation of the coal variables in a selective mining approach.

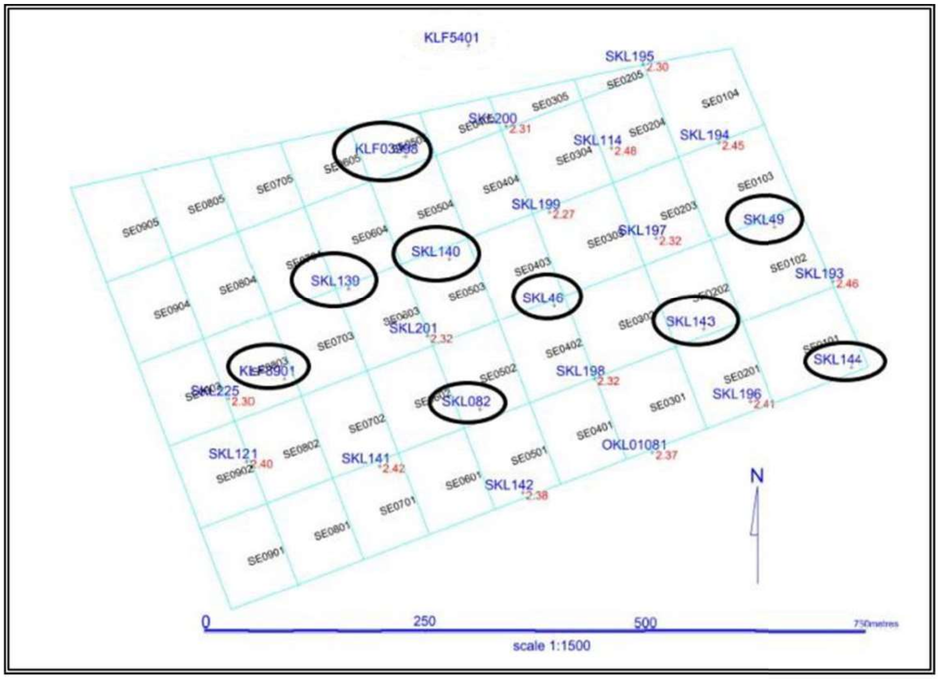


Figure 52: P3 Domain boreholes, indicating location of boreholes to be estimated

Figure 53, 54 and 555 shows the plots derived from the Minex grids for the seam thickness using the MGA, IDW and OK respectively. These grids will be used to estimate the seam thickness in the boreholes encircled in Figure 52 though their values are known as depicted in Figure 48.

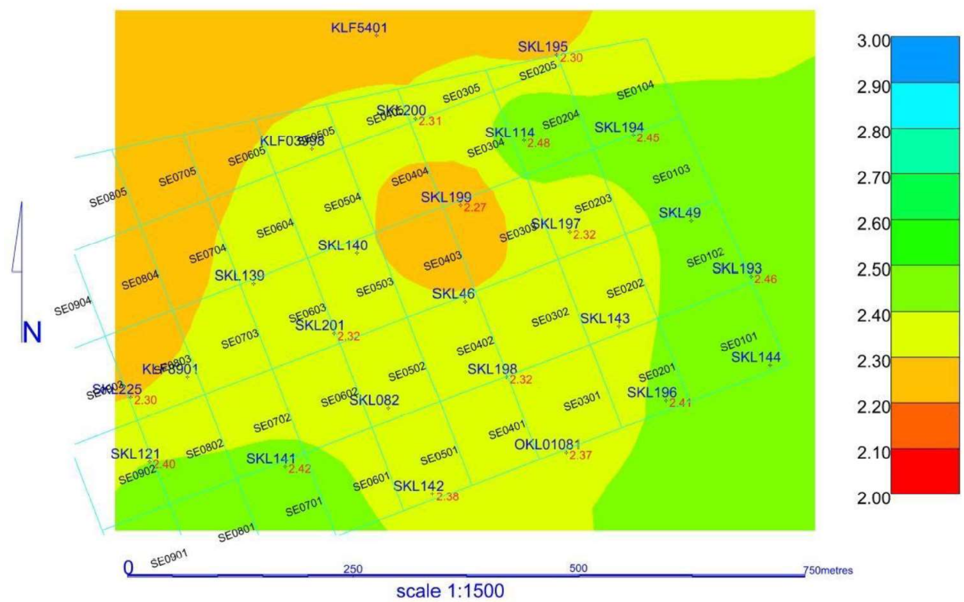


Figure 53: Number 5 Seam thickness plot using the MGA

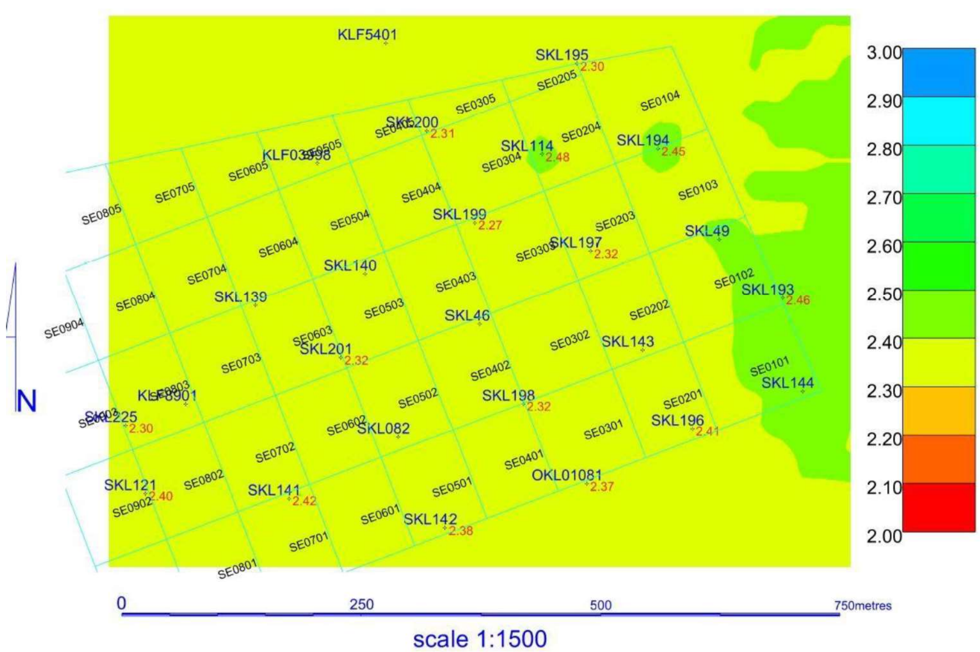


Figure 54: Number 5 Seam thickness plot using IDW

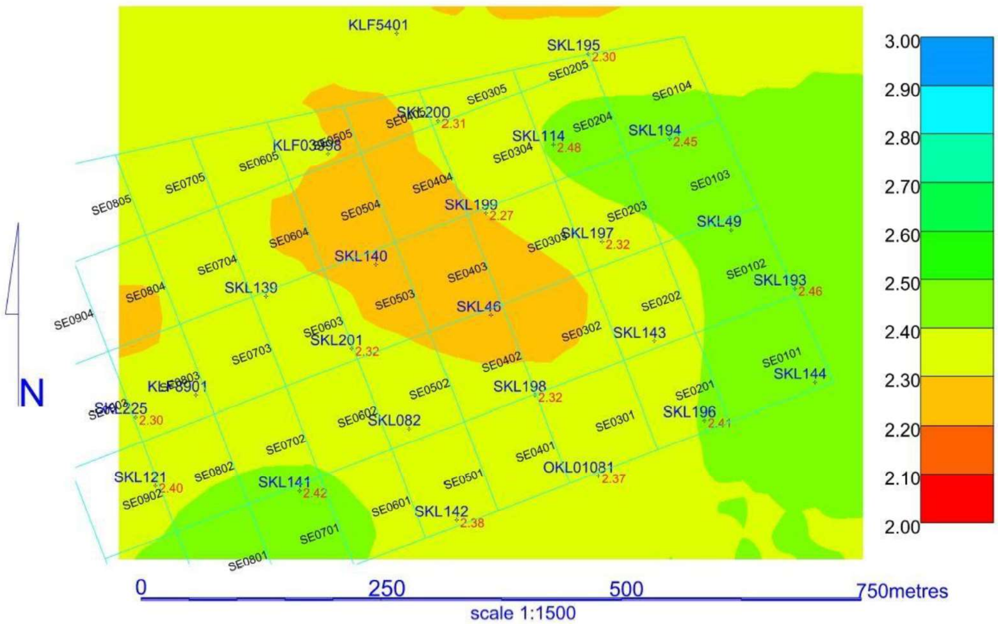


Figure 55: Number 5 Seam thickness plot using OK

As been established in in Figure 38 to 40 for the MGA, Figure 41 to Figure 43 for IDW and Figures 45, 48 and 49 for OK the different estimation techniques produces different results; This observation is also evident in Figure 53 through to 55 for the seam thickness. Cross validation (comparing the new point estimates to the known values as the location) may be used to establish which technique has the least difference compared to the known value.

5.3.1 Cross Validation of Number 5 Seam ST

The Minex software has a borehole predict function, this function uses the grids generated through the different estimation methods to do point estimations of the variable value at the borehole location. Using the grids presented in Figure 53 through to 55 to estimate the values to be compared to the know data, the estimates of the variable using the different estimation methods is tabulated in Table 7 for the ST.

Table 7: Number 5 Seam ST comparison

Borehole ID	Known Thickness (m)	MGA Thickness (m)	Difference (m)	IDW Thickness (m)	Difference (m)	OK Thickness (m)	Difference (m)
KLF03998	2.54	2.31	-0.23	2.34	-0.2	2.31	-0.23
SKL082	2.51	2.35	-0.16	2.36	-0.15	2.36	-0.15
SKL139	2.43	2.31	-0.12	2.34	-0.09	2.31	-0.12
SKL46	2.38	2.3	-0.08	2.35	-0.03	2.27	-0.11
SKL140	2.35	2.3	-0.05	2.34	-0.01	2.28	-0.07
KLF8901	2.27	2.31	0.04	2.35	0.08	2.33	0.06
SKL49	2.35	2.44	0.09	2.41	0.06	2.43	0.08
SKL144	2.31	2.45	0.14	2.41	0.1	2.45	0.14
SKL143	2.04	2.37	0.33	2.38	0.34	2.36	0.32
Average Difference			**-0.01**		**0.00**		**-0.02**

From Table 7 it is observed that for the MGA the difference between estimated and observed ST (m) it ranges between -0.23 and +0.33 m for IDW this range is between -0.2 and +0.34 (m) OK this difference ranges from -0.23 to 0.32 (m). The ST average difference for all three techniques is considerably low and for an open pit mine like KPSS, such can be accommodated for in the conversion of Coal Resources to Coal Reserve through roof and floor loss discounting.

5.3.2 Cross Validation of Number 5 Seam CV

The values in red in Figure 56 will be used through the point estimation method to estimated CV values at the borehole locations where no value is shown.

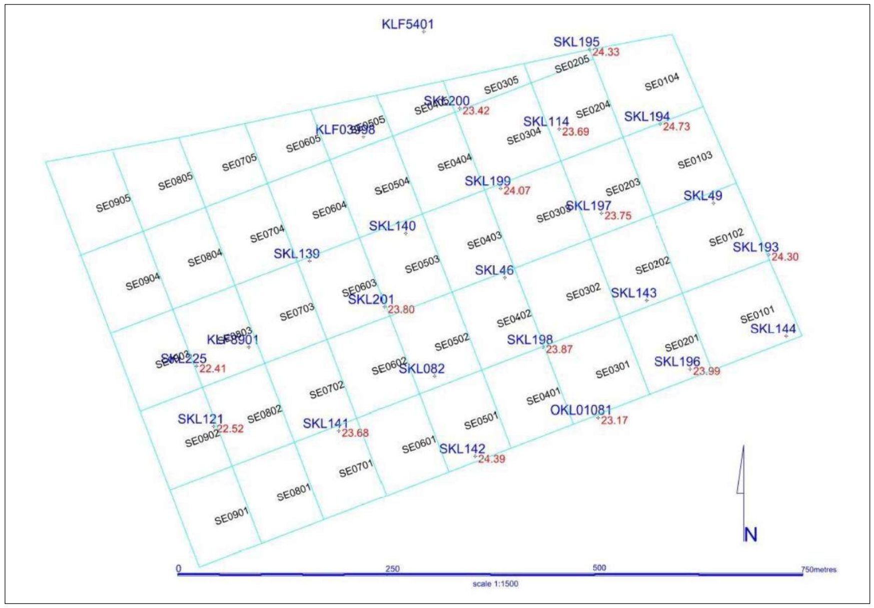


Figure 56: P3 Domain Boreholes indicating Raw CV of the boreholes

From Figure 57, 58 and 59, just like with seam thickness, it is observed that the estimation methods display different results of the CV from each other using the same parameters.

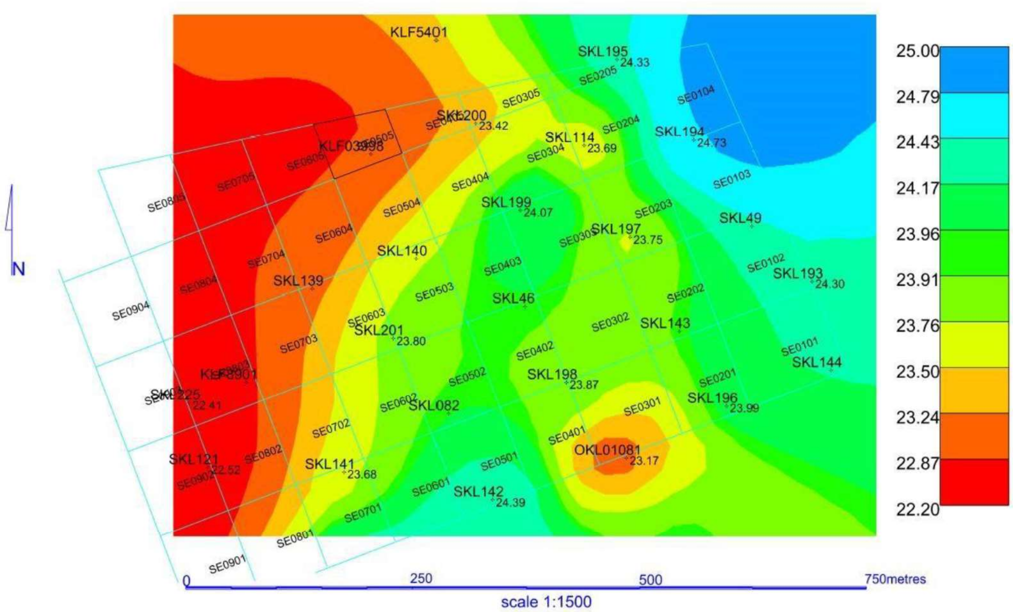


Figure 57: Number 5 Raw CV plot using the MGA

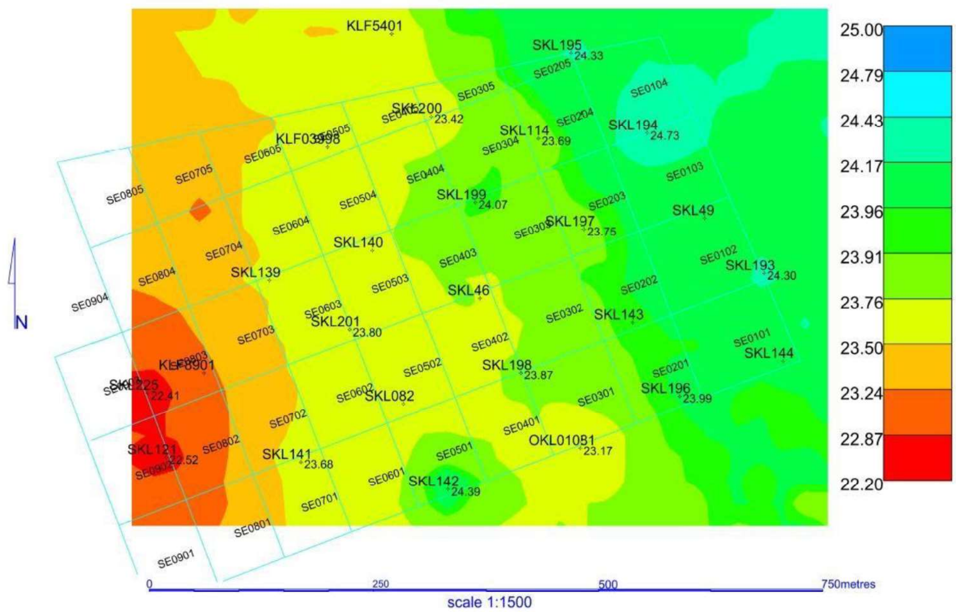


Figure 58: Number 5 Raw CV plot using IDW

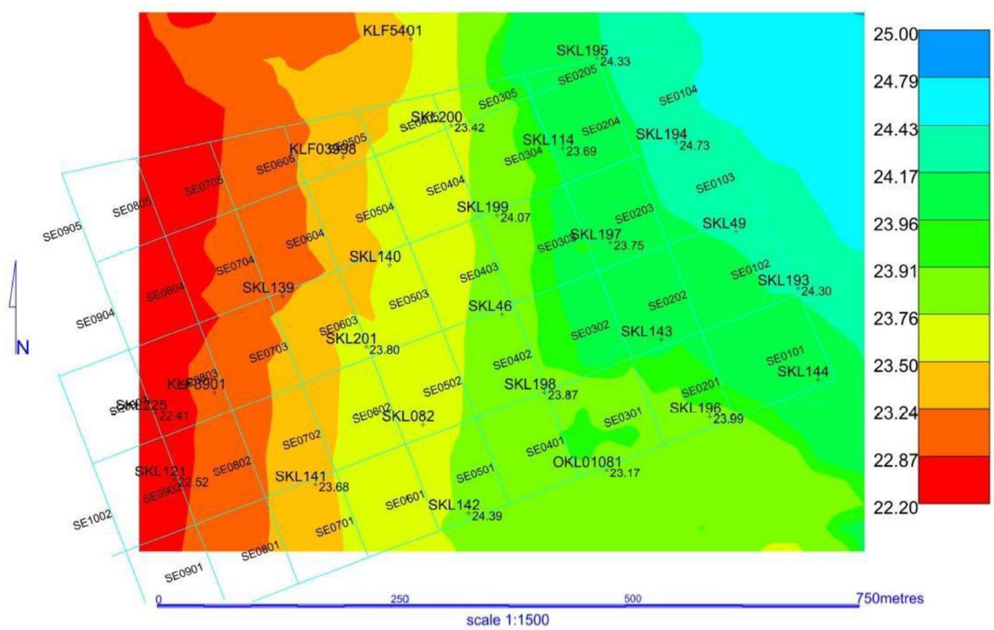


Figure 59: Number 5 Raw CV plot using OK

Though the values are known from laboratory results, the boreholes in Figure 57 to Figure 57 with no CV value attached to it were estimated using the different methods offered in Minex using the borehole predict function. The results of this exercise are presented in Table 8 and in the same table, are compared to the known value through point cross validation.

Table 8: Number 5 Seam Raw CV comparison

Borehole ID	Known CV (MJ/kg)	MGA CV (MJ/kg)	Difference (MJ/kg)	IDW CV (MJ/kg)	Difference (MJ/kg)	OK CV (MJ/kg)	Difference (MJ/kg)
KLF8901	25.21	22.79	-2.42	23.17	-2.04	22.99	-2.22
KLF03998	23.58	22.98	-0.6	23.59	0.01	23.37	-0.21
SKL139	24.53	23.14	-1.39	23.55	-0.98	23.16	-1.37
KLF5401	22.88	23.43	0.55	23.7	0.82	23.48	0.6
SKL140	23.92	23.7	-0.22	23.66	-0.26	23.53	-0.39
SKL143	25.46	23.94	-1.52	23.94	-1.52	24.02	-1.44
SKL46	22.21	23.94	1.73	23.74	1.53	23.84	1.63
SKL082	22.95	23.96	1.01	23.72	0.77	23.68	0.73
SKL144	23.32	24.19	0.87	23.99	0.67	24.11	0.79
SKL49	23.11	24.38	1.27	24.1	0.99	24.22	1.11
Average Difference			**-0.12**		**-0.05**		**-0.13**

Extracted from Table 8, for the MGA the difference is between estimated and observed CV (MJ/kg) this ranges from -2.42 to +1.73, this could have an impact on the extraction of the coal seam; for IDW this range is between -2.04 and +1.53 MJ/kg, again considerable but less than for the MGA method and, in the case of the OK this difference ranges from -2.22 to 1.63 MJ/kg, less than for the MGA but greater than in the case of the IDW.

Introduction of contamination during the extraction of the coal negatively impacts the in-situ qualities of the coal and also the processing thereof, having a large difference in the estimated values may lead to the miss-allocation of coal based on quality. It is very imperative that the estimation method which yields the least differences be used to reduce the above mentioned risk. Based on the results in Table 8, the IDW methods has the least average difference.

5.4 Discussion on estimation methods

It has been experienced that the MGA and the IDW estimation methods are rather very user friendly and straight forward to use once the data has been imported into the software for the gridding process. The OK method on the other hand introduces room for human error as the process of gridding with this method requires more manual input and geostatistical understanding from the user.

Comparing the three estimation methods provided in the Minex software for the seam thickness and raw CV estimations some differences have been observed. As shown in Table 7, the seam thickness estimation values, though there are certain instances where the estimation is either too high or too low compared to the known values at the borehole location, are not the same. The results of all the methods seem to follow the same trend, where one is higher than the known value, the others are also higher, same applies to when one estimation is lower than the known value. The differences in ST estimations however is not very significant considering the coal mining industry

More variability is observed when comparing the raw CV estimations for the estimation methods. Though the trend remains where when one estimate is very high, so is the others, it is observed that when dealing quality variables such as CV and Ash a more precise estimation method should be used.

Looking at the average differences achieved from the estimation methods, it is observed that the IDW estimation method in general estimates closer values to the known values for both seam thickness and raw CV.

Based on these observations, the IDW estimation method has been selected as the preferred estimation method to establish an optimal method for the Number 5 Seam coal extraction.

6 Optimisation of the Coal extraction in Domain P3

The Number 5 seam in the P3 Domain ranges in ST from 2.04 m to 2.71 m this thickness opens the possibility of apply different mining methods for the coal in this domain. Coal quality results and borehole logs have identified the upper 0.9 m on average of the Number 5 Sea in the P3 Domain to contain shale and sandstone intercalation and thus resulting in the overall quality of the coal to be low.

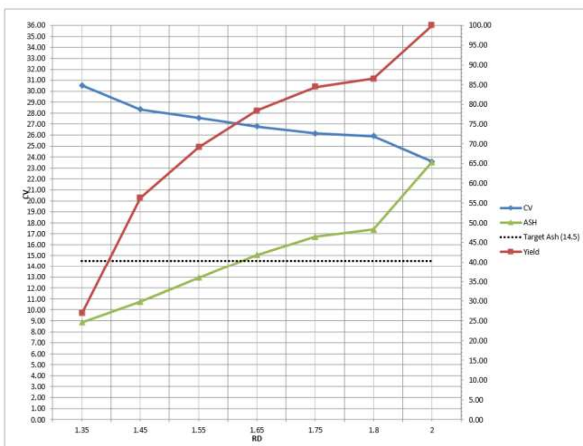
This sections explores the possibility of either extracting the Number 5 Seam coal in the P3 Domain as composite or with a selective mining approach, the mining method which will be more practical and yields more revenue for the operation will be the selected method by which the coal will be extracted.

6.1 Number 5 Seam composite extraction for the P3 Domain

Based on the in-situ coal variables, using the inverse distance estimation method, the Number 5 Seam in the P3 Domains covers an area of 268,198 m^2 hosting 964,225 tonnes of Number 5 Seam coal. The P3 Domain

Number 5 Seam has an average raw CV and Ash of 23.58 MJ/Kg and 23.53% respectively. Based on these qualities, this coal can either be used to upgrade low quality seams through blending or go through the coal handling and processing plant to be washed to achieve the South32 customer specification for both export and domestic.

Figure 59 indicates the washability curve for the general processing of this coal assuming 100% of the coal is processed through the plant.



RAW Qualities	
RD	1.52
Ash	23.53
CV	23.58
FC	46.16
IM	3.43
TS	1.42
VM	26.88

Theoretical / Borehole Yield		
Primary	Secondary	Total
75.02	11.51	86.53

Practical / Plant Yields		
Primary	Secondary	Total
67.02	7.51	74.53

Cumulative wash table																	
1.35			1.45			1.55			1.65			1.75			1.8		
ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD
8.86	30.53	26.82	10.73	28.35	56.29	12.92	27.57	69.12	15.05	26.78	78.40	16.71	26.15	84.37	17.39	25.90	86.53

Figure 60: Number 5 Seam composite washability curve

From Figure 60, it may be derived that theoretically (based only on borehole quality results) to achieve the 14.5% Ash as specified by the export customer, the coal will have to be washed at a density of 1.62 kg/m^3 where the export product coal tonnes that will be achieved is 75.02% of the total in-situ Coal Resources. The middlings, which are the domestic customer specifications are 11.51% of the in-situ Coal Resources. Furthermore, Figure 60 indicates the practical yield, taking into consideration mining factors such as contamination, coal recovery and plant efficiency, the primary yield is estimated to be 67.02% and the middlings at 7.51% yield of the in-situ Coal Resources. The product is calculated in Table 9

Table 9: Number 5 Seam Composite products

Product	In-situ Tonnes	Yield	Tonnages	Revenue
Primary	964,225	75.02%	723,362	R941 093, 435
Middlings		11.51%	110,982	R66 034, 467
Total		86.53%	834,344	R1 007 127, 902

From Table 9 using the theoretical yield obtained from Figure 59 and based on the 26 March 2021 coal prices depicted in Figure 11, mining the Number 5 Seam coal composite and processing it through the plant for the 5950 NAR and the 4800 NAR products will generate about R1 billion.

6.2 Number 5 Seam selective mining for Domain P3

The P3 Domain boreholes logs were investigated for the number of samples taken per borehole and the practicality of using these samples to establish a selective mining splitting horizon. Figure 61 indicates the number of samples taken per borehole in the study area, from these boreholes fifteen boreholes have two or more samples and ten only one sample taken of the number 5 seam.

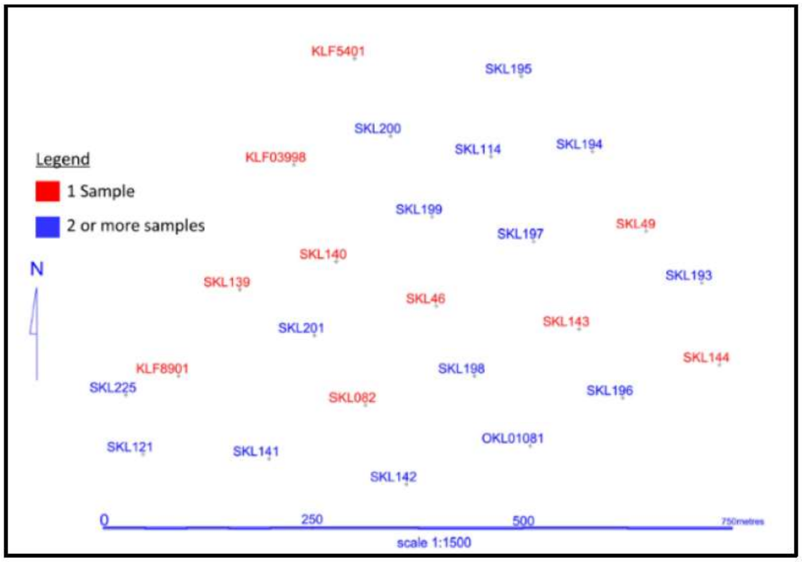


Figure 61: P3 Domain boreholes indicating number of samples per borehole

Figure 62 shows that the sample of SKL140 as representation of how the ten boreholes where one sample was taken were sampled. From Figure 62 it was observed that the sample (Z01) was taken from 34.57 – 36.92 m whereas, also indicated in Figure 62, the sampling should have been done with Z01 being from 34.57 – 35.36 m and Z02 from 35.36 – 36.92 m.

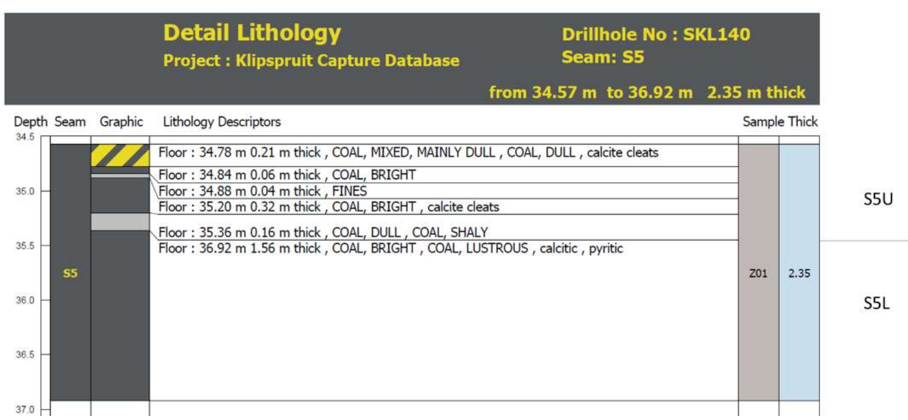


Figure 62: Detailed log of SKL140 indicating how sampling was done versus number 5 seam splitting horizons

There are two boreholes that have more than one sample however the sampling was not representative of the splitting analogy. Figure 63 indicates how samples Z01, Z02 and Z03 were taken. Analysing the detailed log of the borehole, Figure 63 also indicates how sampling should have been done.

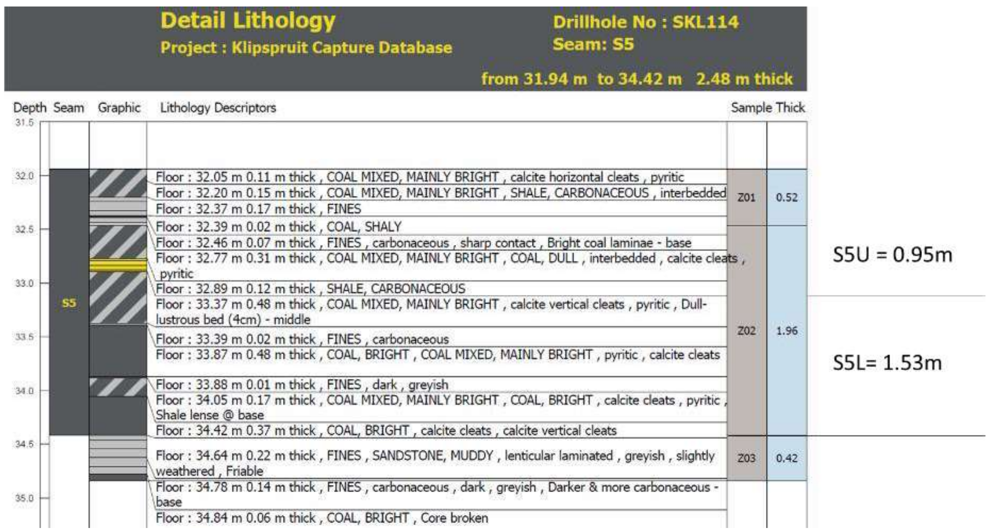


Figure 63: Detailed log of SKL114 indicating how sampling was done versus the number 5 seam splitting horizons

Figure 64 depicts how the remaining thirteen boreholes were sampled, defining the number 5 seam splitting horizon. These boreholes will be used to estimate what the CV and Ash values would be if the above-mentioned holes were sampled as per the outlined Number 5 Seam splitting horizons using the estimation methods presented in Minex.

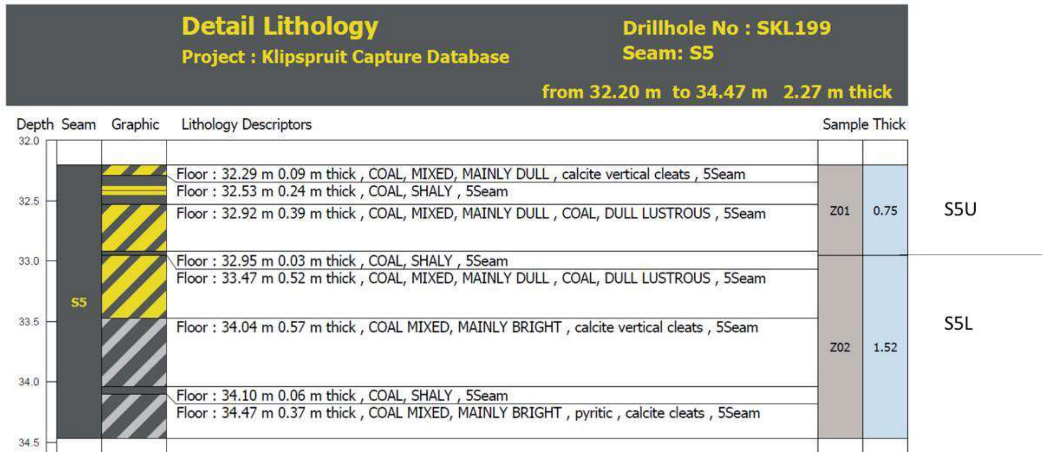


Figure 64: Detailed log of SKL199 indicating how sampling was done versus the number 5 seam splitting horizons

All the one sample boreholes in Figure 61 and the 2 two samples boreholes which were erroneously sampled (SKL114 and SKL142) will not be included for the extraction optimisation analysis in the gridding process in Minex. The S5U and S5L seam thickness will be estimated for comparison of the IDW estimates to the known values of the twelve boreholes then subsequently the Ash and CV thereof.

Based on the detailed logs of each borehole in the P3 Domain the number 5 seam was split into 2 portions, namely the S5U and S5L; as shown in Table 10. These horizons will be used to optimize the in-situ Number 5 Seam qualities for extraction and processing. The CV and Values of the boreholes in Table 10 are as per the samples and are represented in the spatial plots in Figure 65 and 66 respectively for the S5U estimations and Figure 69 and 70 for the S5L estimations. On average, based on the boreholes shown in Table 10, the average S5U and S5L ST is 0.75 and 1.62 m respectively, this is expected to corelate to the ST to be estimated.

Table 10:Boreholes in the P3 Domain indicating the split horizon of the Number 5 seam

BOREID	FROM	TO	Split Seam Thickness (m)	Total Seam Thickness (m)	SEAM NAME
KLF03998	33.36	34.34	0.98	2.54	S5U
	34.34	35.9	1.56		S5L
KLF5401	32.3	32.62	0.32	2.4	S5U
	32.62	34.7	2.08		S5L
KLF8901	36.5	37	0.5	2.27	S5U
	37	38.77	1.77		S5L
OKL01081	34.2	35.25	1.05	2.37	S5U
	35.25	36.57	1.32		S5L
SKL082	35.97	36.91	0.94	2.51	S5U
	36.91	38.48	1.57		S5L
SKL114	31.94	32.89	0.95	2.48	S5U
	32.89	34.42	1.53		S5L
SKL121	37.55	38.05	0.5	2.4	S5U
	38.05	39.95	1.9		S5L
SKL139	35.72	36.66	0.94	2.43	S5U
	36.66	38.15	1.49		S5L
SKL140	34.57	34.88	0.31	2.35	S5U
	34.88	36.92	2.04		S5L
SKL141	34.73	35.24	0.51	2.42	S5U
	35.24	37.15	1.91		S5L
SKL142	34.67	35.52	0.85	2.38	S5U
	35.52	37.05	1.53		S5L
SKL143	29.08	29.8	0.72	2.04	S5U
	29.8	31.12	1.32		S5L
SKL144	26.58	26.93	0.35	2.31	S5U
	26.93	28.89	1.96		S5L
SKL193	25.75	26.58	0.83	2.46	S5U
	26.58	28.21	1.63		S5L
SKL194	25.65	26.6	0.95	2.45	S5U
	26.6	28.1	1.5		S5L
SKL195	28.53	29.37	0.84	2.3	S5U
	29.37	30.83	1.46		S5L
SKL196	28.22	28.63	0.41	2.41	S5U
	28.63	30.63	2		S5L
SKL197	31.51	32.3	0.79	2.32	S5U
	32.3	33.83	1.53		S5L
SKL198	35.05	36	0.95	2.42	S5U
	36	37.47	1.47		S5L
SKL199	32.2	32.95	0.75	2.27	S5U
	32.95	34.47	1.52		S5L
SKL200	31.44	32.24	0.8	2.31	S5U
	32.24	33.75	1.51		S5L
SKL201	35.33	36.11	0.78	2.32	S5U
	36.11	37.65	1.54		S5L
SKL225	35.48	36.2	0.72	2.3	S5U
	36.2	37.78	1.58		S5L
SKL49	27.33	28.32	0.99	2.35	S5U
	28.32	29.68	1.36		S5L
SKL46	33.96	34.86	0.9	2.38	S5U
	34.86	36.34	1.48		S5L

6.2.1 S5U estimations

Figure 62 shows the S5U seam thickness plot as derived using the IDW estimation method. From the seam thickness plot, it may be observed that the seam thickness ranges from 0.31m to 1.05m.

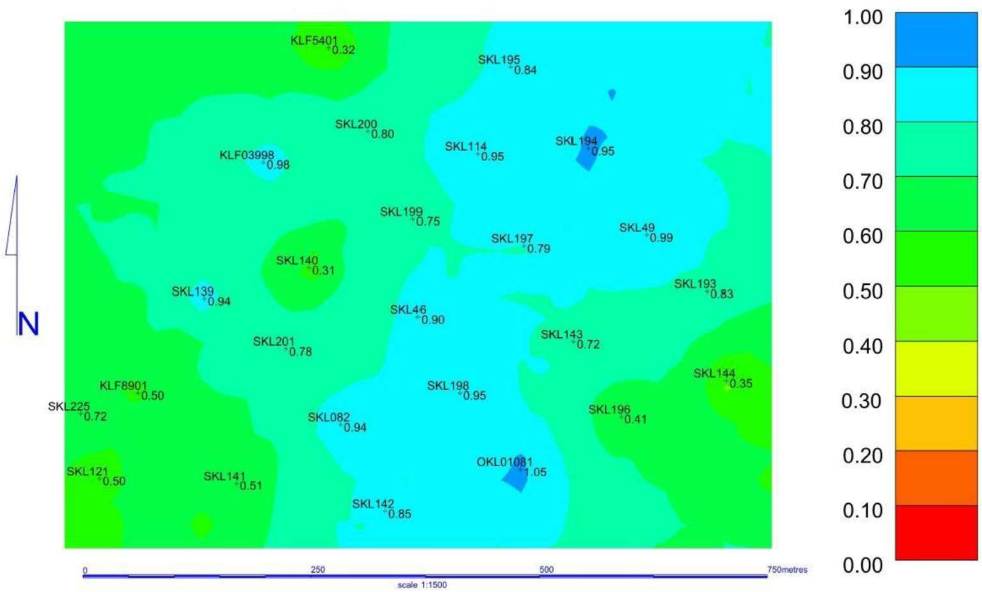


Figure 65: S5U Seam thickness plot (m) IDW spatial distribution

The boreholes where the Number 5 seam was taken as one sample and those where the seam was not sampled defining the selective mining splitting horizon have their qualities removed from the geology model and will be estimated using the IDW estimation method. As can be observed in Figure 65 and Figure 66, the relationship between CV and Ash remains. These figures show the S5U Raw CV and Raw Ash respectively, from these plots it has been observed that the Raw CV for the S5U ranges from 14.20 to 21.27 MJ/kg while the Raw Ash ranges from 29.00 to 49.28%

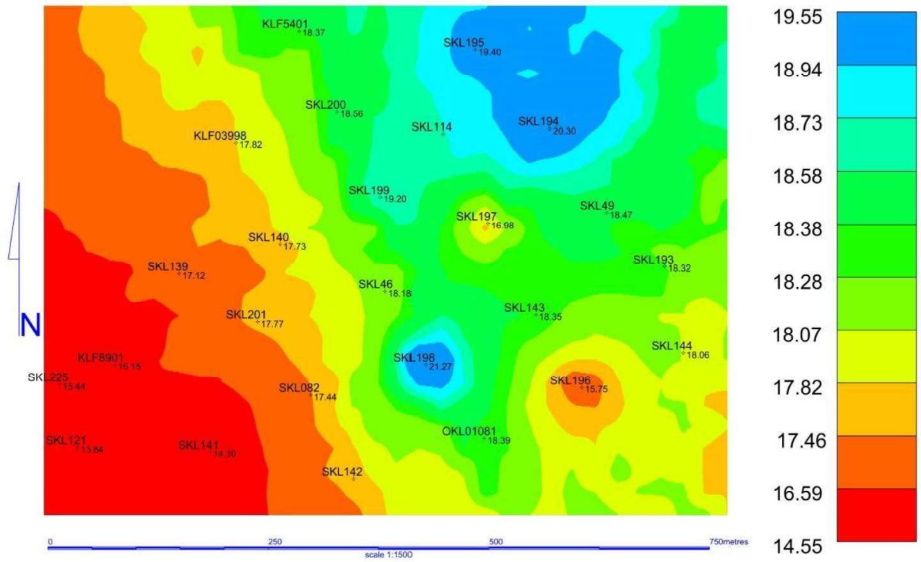


Figure 66: S5U Raw CV plot (MJ/kg) IDW spatial distribution

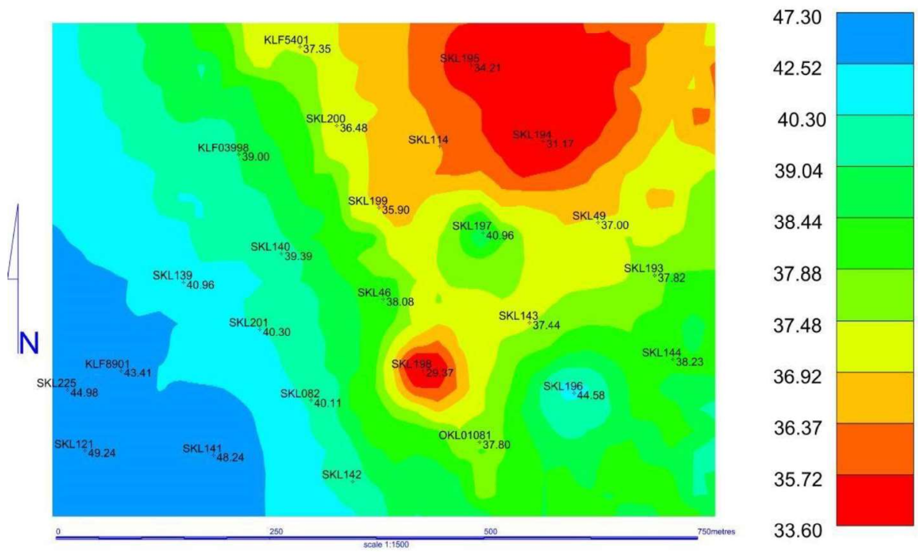


Figure 67: S5U Raw Ash plot (%) IDW spatial distribution

Based on the IDW grids depicted in Figure 64 to 66, Table 11 shows the S5U Minex borehole prediction for the boreholes selected for the S5U coal variable estimations.

Table 11: S5U coal IDW estimates ST, Raw CV and Ash

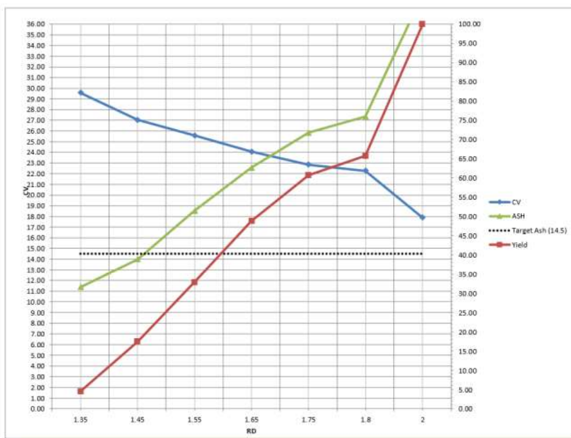
Bore_ID	Seam	From	To	Thickness (m)	Raw CV (MJ/kg)	Raw Ash (%)
KLF03998	S5U	33.25	34.15	0.9	17.82	38.98
KLF5401	S5U	31.43	31.88	0.46	18.43	37.15
KLF8901	S5U	36.41	36.97	0.56	16.27	43.08
SKL082	S5U	35.83	36.7	0.87	17.38	40.23
SKL139	S5U	35.6	36.49	0.89	17.3	40.45
SKL140	S5U	34.35	34.84	0.5	17.74	39.36
SKL143	S5U	29.59	30.33	0.75	18.44	37.19
SKL144	S5U	27.07	27.48	0.41	18.16	37.95
SKL46	S5U	33.97	34.83	0.86	18.15	38.16
SKL49	S5U	27.54	28.48	0.94	18.44	37.02
SKL114	S5U	30.9	31.76	0.86	18.72	36.39
SKL142	S5U	34.06	34.87	0.82	17.65	39.54
Average				0.74	17.88	38.79

The estimated S5U ST in the boreholes presented in Table 11 ranges from 0.41 to 0.9 m with an average of 0.74 m thickness which is correlates very well with the ST from Table 10 of the boreholes that were correctly sampled. Taking the ST correlation into consideration, it may be assumed that the CV and Ash values estimated are also correlating and may be used in the modelling of the P3 Domain S5U coal.

6.2.2 S5U processing

The S5U coal covers the same area as established for the Number 5 Seam composite as outlined in section 6.1. The area host 350,588 tonnes with an average seam thickness of 0.75 m. The average raw CV and Ash of the S5U is 17.88Mj/Kg and 38.78% respectively as derived from the borehole results of the boreholes sampled correctly and correlating the estimated values in Table 11. Based on these qualities, this coal needs to go through the coal handling and processing plant to be washed to achieve the South32 customer specification for both export and domestic markets.

Figure 67 indicates the washability curve for the general processing of this coal assuming 100% of the coal is processed through the plant.



RAW Qualities	
RD	1.72
Ash	38.78
CV	17.88
FC	37.24
IM	2.96
TS	0.73
VM	21.06

Theoretical / Borehole Yield		
Primary	Secondary	Total
22.31	43.42	65.73

Practical / Plant Yields		
Primary	Secondary	Total
14.31	39.42	53.73

Cumulative wash table																	
1.35			1.45			1.55			1.65			1.75			1.8		
ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD
11.37	29.58	4.51	14.00	27.04	17.46	18.52	25.57	32.92	22.57	24.06	48.75	25.84	22.84	60.73	27.34	22.27	65.73

Figure 68: S5U washability curve

From Figure 67, it may be derived that to achieve the 14.5% Ash as specified by the export customer, the coal will have to be washed at a 1.48 kg/m^3 density where the export product yield that will be achieved is 22.31%. The secondary, which are the domestic customer specifications is 43.42%. The practical yield for the primary and secondary products show to be 14.31% and 39.42% respectively.

Table 12: S5U products

Product	In-situ Tonnes	Yield	Tonnages	Revenue
Primary	350,588	22.31%	78,216	R101 759,254
Middlings		43.42%	152,225	R90 574,059
Total		65.73%	230,441	R192 333,313

From Table 12 using the theoretical yield obtained from Figure 67 and based on the 26 March 2021 coal prices, mining the S5U and processing it through the plant for the 5950 NAR and the 4800 NAR products will generate about R192 million.

6.2.3 S5L estimation

Figure 66 shows the S5L seam thickness plot as derived using the inverse distance estimation method. From the seam thickness plot, it may be observed that the seam thickness ranges from 1.30 to 2.08 m.

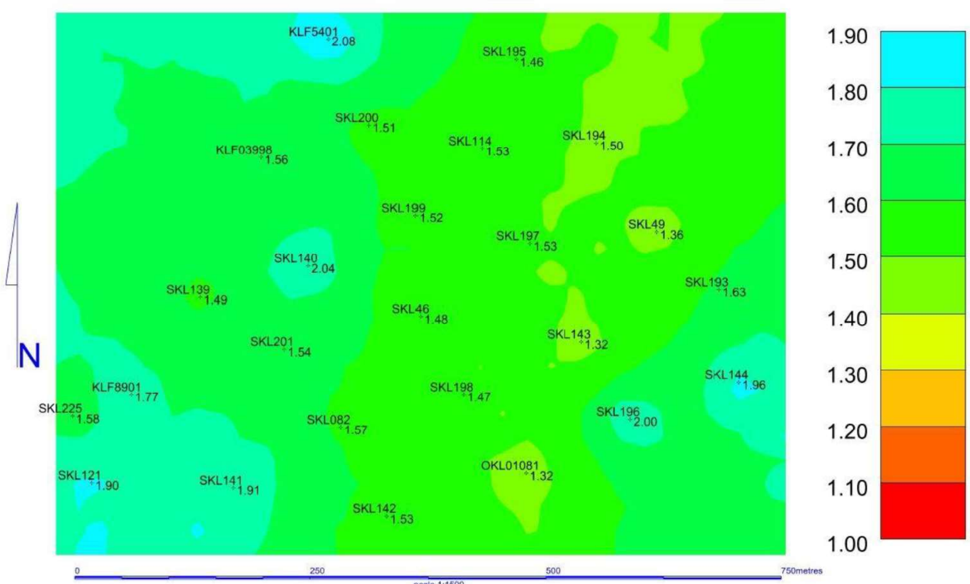


Figure 69: S5L Seam thickness (m) IDW spatial distribution

Figure 69 and 70 shows the S5L Raw CV and Raw Ash respectively, the S5L CV and Ash as derived from these grids ranges from 24.80 to 27.34 MJ/Kg and 12.02% to 20.37% respectively

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These grids will be used to estimate the S5L Raw CV and Ash for the boreholes omitted from the gridding. The results from the Minex borehole prediction function is tabulated in Table 13.

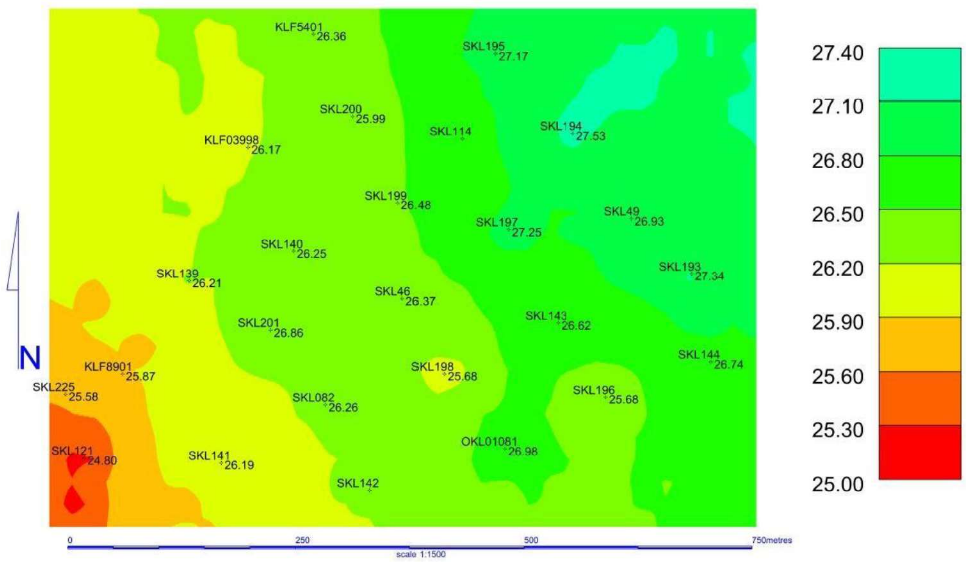


Figure 70: S5L Raw CV (MJ/kg) IDW spatial distribution

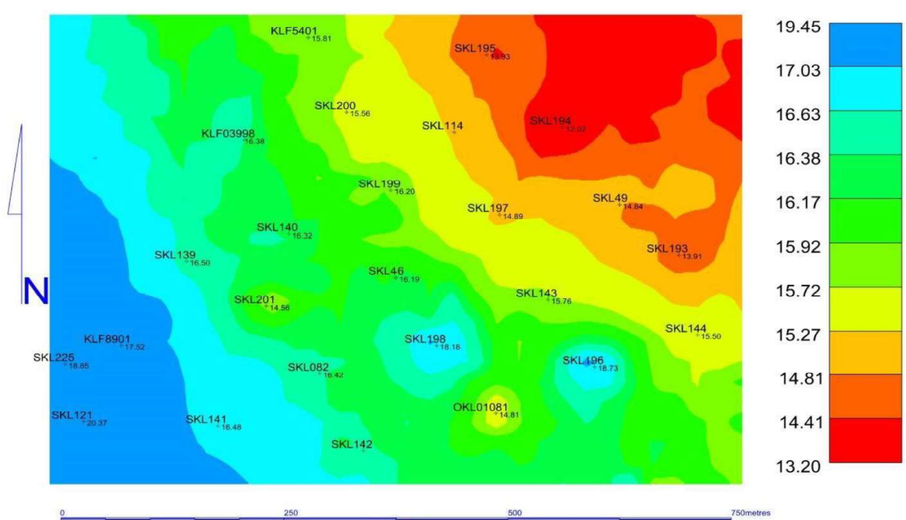


Figure 71: S5L Raw Ash (%) IDW spatial distribution

Table 13: S5L coal IDW estimates ST, Raw CV and Ash

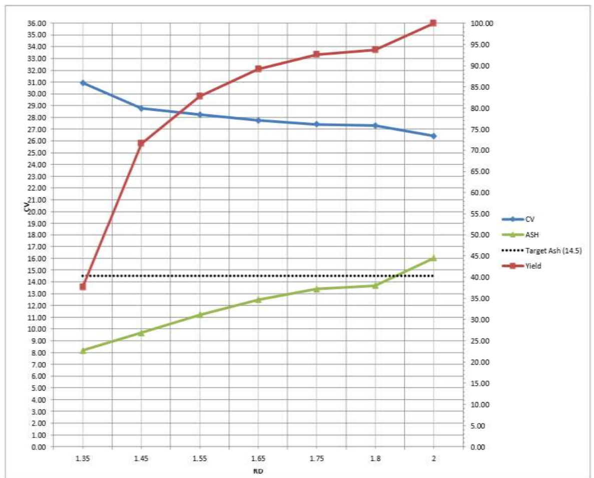
Bore_ID	Seam	From	To	Thickness	Raw CV	Raw Ash
KLF03998	S5L	34.15	35.74	1.59	26.1	16.52
KLF5401	S5L	31.89	33.82	1.94	26.29	16
KLF8901	S5L	36.97	38.72	1.75	25.86	17.53
SKL082	S5L	36.7	38.3	1.6	26.28	16.28
SKL139	S5L	36.49	38.02	1.53	26.26	16.38
SKL140	S5L	34.84	36.71	1.87	26.25	16.32
SKL143	S5L	30.33	31.75	1.41	26.62	15.83
SKL144	S5L	27.48	29.38	1.91	26.68	15.65
SKL46	S5L	34.83	36.34	1.52	26.31	16.33
SKL49	S5L	28.48	29.9	1.42	27.01	14.59
SKL114	S5L	31.77	33.31	1.54	26.67	15.21
SKL142	S5L	34.87	36.44	1.57	26.27	16.44
Average				1.64	26.38	16.09

The estimated S5L ST in the boreholes presented in Table 11 ranges from 1.41 to .94 m with an average of 1.64 m thickness which correlates very well with the ST from Table 10 of the boreholes that were correctly sampled, averaging 1.62 m. Taking the ST correlation into consideration, it may be assumed that the CV and Ash values estimated are also correlating and may be used in the modelling of the P3 Domain S5L coal.

6.2.4 S5L processing

The S5L coal covers the same area as established for the Number 5 Seam composite as outlined in section 6.1. The average S5L thickness in this area is 1.61m resulting in the area having 613,637 tonnes of S5L coal. The average raw CV and Ash of the S5L is 26.4 Mj/Kg and 16.06% respectively. Based on these qualities, this coal can either be processed through the washing plant or crushed at 100% yield and blended directly to the export product to save costs.

Figure 69 indicates the washability curve for the general processing of this S5L coal assuming 100% of the coal is processed through the plant.



RAW Qualities	
RD	1.43
Ash	16.03
CV	26.42
FC	50.13
IM	3.41
TS	1.36
VM	30.51

Theoretical / Borehole Yield		
Primary	Secondary	Total
95.80	4.20	100.00

Practical / Plant Yields		
Primary	Secondary	Total
87.80	0.20	88.00

Cumulative wash table																	
1.35			1.45			1.55			1.65			1.75			1.8		
ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD	ASH	CV	YIELD
8.17	30.92	37.65	9.68	28.76	71.56	11.20	28.22	82.70	12.48	27.74	89.15	13.39	27.41	92.62	13.69	27.30	93.74

Figure 72: S5L washability curve

From Figure 71, it is observed that when the plant washes at its highest density limit of 1.8 kg/m^3, the product produced is 93.74% while the secondary will be the remaining 6.26%. The 93.74% product produced however has a 13.69% Ash, which still exceeds the high-grade export product specification.

Table 14: S5L products

Product	In-situ Tonnes	Yield	Tonnages	Revenue
Primary	613,637	93.74%	572,223	R748 365,544
Middlings		6.26%	37,414	R22 856,137
Total		100%	613,637	R771 221,682

From Table 14 using the theoretical yield obtained from Figure 71 and based on the 26 March 2021 coal prices, mining the S5L and processing it at the plant for the 5950 NAR and the 4800 NAR products will generate about R770 million.

6.3 Discussion

Two extraction methods have been investigated for the extraction of the Number 5 Seam, namely 5 Seam composite extraction and the selective mining approach. As shown in Table 15, selective mining of the Number 5 Seam, theoretically, will yield on average lower quantities of product whether the S5L is washed through the processing plant or not.

Table 15: Theoretical comparison between mining methods (Tonnes)

	None Selective mining			Selective mining								Difference	
	S5 Composite			S5U			S5L			S5L Washed	S5L not washed		
	In-situ Tonnes	Yield	Product tonnes	In-situ Tonnes	Yield	Product tonnes	In-situ Tonnes	Yield	Product tonnes	Total	Total	S5L Washed	S5L not washed
Primary		75.0%	723 362		22.31%	78 216		93.74%	575 223	653 440	691 853	- 69 922	- 31 508
Secondary	964 225	11.5%	110 982	350 588	43.42%	152 225	613 637	6.26%	38 414	190 639	152 225	79 657	41 243
Total		86.5%	834 344		65.73%	230 441		100%	613 637	844 078	844 078	9 735	9 735

Financially, having produced lesser product volumes, as depicted in Table 16, revenue will also decrease.

Table 16: Theoretical comparison between mining methods (Revenue)

		Selective mining				Difference	
	S5 Composite	S5U	S5L	S5L Washed	S5L not washed		
	Revenue	Revenue	Revenue	Revenue	Revenue	S5L Washed	S5L not washed
Primary	R941 093 435	R101 759 254	R748 365 544	R850 124 798	R900 100 991	-R90 968 637.01	-R40 992 444.27
Secondary	R66 034 467	R90 574 059	R22 856 137	R113 430 197	R90 574 059	R47 395 729.54	R24 539 592.20
Total	R1 007 127 902	R192 333 313	R771 221 682	R963 554 995	R990 675 050	-R43 572 907.47	-R16 452 852.07

What can be deduced from Table 15 and Table 16 is that the Number 5 Seam coal should be processed through the washing plant for the company to generate more revenue. A contributing factor is that the washing plant is limited to wash at 1.8kg/m^3 as its highest density and is also configured to only blend to the secondary product instead of the primary.

As was observed in Figure 71, the product achieved when washing the S5L is still of higher quality than the 6000 NAR specifications for Ash. To achieve the 14.5% Ash, the plant would need to be redesigned to wash at a 1.90 kg/m^3 density, this implies more costs from the company.

A challenge further exists, as observed in Figure 67, the TS for the S5L is above the export product specifications, it sits at 1.36% instead of less than 0.44% as specified for the 6000 NAR product; this means a blending strategy needs to be developed to control the sulphur content to customer specification.

Furthermore, the current configuration of the Klipspruit blending conveyor is set up to only blend into the secondary product, changing this set up or trucking the crushed S5L to the primary product will imply additional expenditure for the company.

7 Conclusions

The research study was set out to compare the different geostatistical estimation methods imbedded in the Minex software, and has shown that the understanding of the different methods of geostatistical resources estimation plays an imperative role in the accuracy of the Resources and Reserves reported. It will be of value for the modeller to interrogate which method best represents the data that is being modelled.

In the case of the Number 5 Seam at KPSS, IDW technique has shown to estimate the least deviation from the true value for the ST and CV compared to the MGA and the OK estimation methods. The OK method, though believed by many to be the best, requires more knowledge & understanding of specifically variography analysis and variogram modelling that is the basis of it, this will result in more accurate estimates.

The selection of an appropriate geostatistical method allows for more accurate resource estimation of variable values in the deposit where data does not exist.

The delineation of different domains prior to modelling of the coal seam is imperative, this allows the modeller to have a clear understanding of the geology affecting the data that is being used for the estimations. An understanding of the geology further empowers the modeller to make more informed decision during the Resource classification stage through to the advice given during the extraction phase.

It may be concluded for the study area that extraction of the number 5 seam as a composite seam will yield more revenue compared to when the seam is extracted through selective mining. It is further concluded that mining the Number 5 Seam composite will eliminate the need for the establishment of blending strategies.

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