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Potential Assessment of Coal Deposits in Gamo Zone, Kucha Woreda, Ethiopia

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Abstract

The present study was conducted to assess the potential occurrence of coal deposited in the Gamo zone, Kuccha woreda, Daho Kebele. It also aims to determine the quality and quantity of coal through field and laboratory techniques. Nineteen coal samples and five rock samples were collected from outcrops, test pits and trench sites and analysed for major and minor oxides of rock units and coal samples to determine the percentage of moisture, volatile matter, fixed carbon content, ash and calorific value in the laboratory of the Geological Survey of Ethiopia using AAS, adiabatic caloric matter, gravimetric and proximate analyses, respectively. The geologic setup of the study area is predominantly characterized by basaltic rocks and rhyolite interbedded/intercalated with coal seams of different thicknesses ranging from 0.3 m to 2.62 m. A geological map with a 1:25,000 scale and three potential coal occurrence maps with a 1:10,000 scale were prepared based on field surveys and laboratory results. Analysis of the coal samples revealed that the moisture content ranged from 1.62-12.84%, the volatile matter content ranged from 6.53-32.98%, the fixed carbon content ranged from 0.04-55.78%, the ash content ranged from 10.34 to 90.06%, and the calorific value ranged from 1007.24 to 6873.76Cal/gm. This indicates that compared with the ASTM international standards, the rank of kucha coal lies on the lignite to subbituminous. Fifteen test pits were dug in all potential coal sites, and the average thickness of the coal seams ranged from 1.06 m to 1.14 m. According to the geophysical survey of the vertical electrical sounding results, a coal layer with an average thickness ranging from 0.62 m to 2.62 m was identified. Based on the log results of pits, geophysical results and areal coverage of coal deposits, the study area is estimated to have 744,174.96 tons of coal.

Keywords: *Coal; Energy; Minerals; Trench; Calorific value.*

1. Introduction

Coal is a chemically and physically heterogeneous "combustible'' sedimentary rock consisting of both organic and inorganic materials [1]. It is mostly enriched with organic constituents, such as carbon with minor concentrations of hydrogen, oxygen, sulphur and nitrogen, along with a few inorganic constituents, minerals, and water [2]. It is a solid usually composed of brown or black carbon-rich material that most often occurs in stratified sedimentary deposits [3]. During and after the deposition of plant remains in sedimentary basins, the organic remains undergo a sequence of physical, biochemical and chemical changes (diagenesis and catagenesis), which results in a series of coals. The series begins with unaltered plant material and peat, which continues with increasing rank through brown coal, bituminous coal and finally anthracite [4]. The transformation of vegetable matter into peat and then to coal is regarded as the biochemical and physicochemical stages of coalification, respectively [5].

The original plant (but can include animal) material has a vast morphological and chemical variety even before being incorporated into the peat. After plant materials are deposited, a range of biochemical processes occur (peatification), which considerably alters the morphological, physical and chemical nature of the existing organic material by introducing new materials and precipitates. Finally, through humification, burial diagenesis (coalification) with increasing temperature has a significant effect on all the individual particles and on the coal as a whole [6].

The coal deposits have specific plant precursors that are marked by the regional history followed by the depositional conditions. This causes enrichment or depletion of different elements, phases or minerals that give rise to a unique fundamental code that characterizes coal. The mineral composition and association between mineral matter and organic matter mark the genetic code. Then, the composition can be interpreted to infer the type, quality, and genesis of coal [2].

Energy is one of the basic inputs for economic development and human survival. Energy is needed as an input in industry, agriculture, mining, construction and service-giving organizations. The availability of energy at a reasonable cost has always become a condition of industrial growth and economic and social progress. Ethiopia is one of the countries that depends upon imported petroleum products. The need for domestic fuel in the country is the major factor for deforestation and soil degradation [7]. To overcome this problem, geological studies were carried out to determine a valuable amount of coal deposits in the country. Coal deposits could play an important role in the future energy budgets of Ethiopia.

Intertrappean coal and oil shale deposits are distributed on the southwestern and central plateaus of Ethiopia (the Delbi-Moye, Yayu, Lalo-Sapo, Sola and Chida, Chilga, Nejo, and Mush Valley Basins) [7].

There are four main coal types: lignite, subbituminous coal, bituminous coal and anthracite. These different types of coals have a certain set of physical and chemical characteristics distinguished by different approaches, including proximate, ultimate, total organic carbon (TOC), calorific value (CV) and maceral analysis.

The proximate analysis of coal determines the moisture, volatile matter (VM), ash and fixed carbon (FC) contents. Chemical analysis is the ultimate approach for characterizing coals according to the amount of principal chemical elements such as carbon, hydrogen, oxygen, nitrogen and sulphur [8]. The TOC is the amount of organic matter present in the unit, and CV indicates the energy value in the coal, whereas maceral analysis is the petrography approach used to identify maceral types. The geochemistry of coal addresses the origin, formation, and environmental effects of organic and inorganic substances in the coal and appraisal of the mineral deposits related to coal [9].

The occurrence of coal in Ethiopia has been studied by different researchers, and lignite varieties are known to occur in many areas of Ethiopia (e.g., Gonder, Wollega, Showa, Kefa, and Welo) [10]. Further investigations and studies conducted to date have inferred that intertrappean coal and oil shale deposits are distributed on the southwestern and central plateau of Ethiopia (Delbi-Moye, Yayu, Lalo-Sapo, Sola and Chida, Chilga, Nejo, Mush Valley Basins) [11]. The coal found in these areas is characterized in terms of CV, proximate and ultimate analysis, sedimentology, palynology, depositional environment, mapping of the surface and subsurface of the resource, structural orientation and relative position using geophysical methods and drilling [7,11].

2. Description of the study area

2.1. Location and accessibility

The study area is located in Kucha woreda, Gamo zone, southern Ethiopia, approximately 549 km from Addis Ababa city and 274 km from Hawassa city. The geographical location of the study areas is bounded between 314000-322000 m E and 720000-726000 m N.

The study area is accessible through an asphalt road that runs from Hawassa to Wolaita Soddo and a gravel road along Wolaita Soddo-Selamber-Moreka-Daho. There are further local gravel roads and foot trials that connect rural local people from their home area to the town. This helps to search for and easily access possible exposures far from the main road.

3. Methodology

Different approaches were used to achieve the objectives of the study, including gathering remote sensing data, satellite images and aerial photographs and analysing them in Arc GIS 10.1 software and Global Mapper 11, in which a base map was prepared; IPI2WIN geophysical software was used to plot the VES data; and the GCDkit analytical tool was used for geochemical analysis. This was followed by fieldwork, analysis and synthesis, and data interpretation.

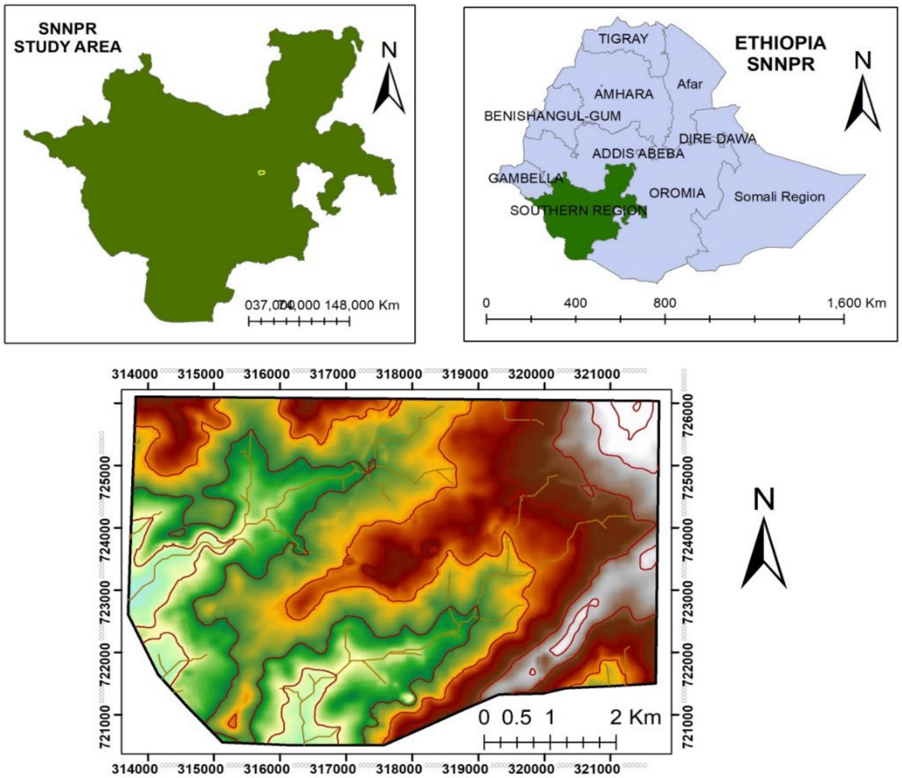


Figure 1. Map of the study area.

3.1. Data collection

All lithologies, structures, thicknesses of coal seams, associated materials and alterations of the rocks were studied and recorded in the field, and representative 90 coal samples and five whole-rock samples were broken manually with a sledgehammer, and fresh samples were collected, labelled and well described. Finally, fifteen pits and eight trenches were dug manually along the proposed lines, their cross-sectional coal seams were described, and their thicknesses were measured with a tap meter.

The electrical resistivity method accomplished by applying the VES technique, which measures the variation in the electrical resistivity with depth, was employed. A Schlumberger array for electrode separation was used in this study by applying a half spacing of the current electrode (AB/2) starting from 1.5 to 150 m in steps. This involves the spacing of four electrodes with two current electrodes widely spaced outside and two potential electrodes closely spaced within them along the survey profile. In this array, the potential MN electrodes can be fixed, while the current electrodes A and B can be changed. The practical advantage of this approach is to minimize the effects of electrical noise. The aim of using this technique is to cover and reach the depth of the coal seam prone to background information obtained from the study area. Two VES points, covering the suspected coal-deposit area1 along a profile-oriented northwest–southeast direction. This was carried out at the 50 m inter-VES point. The instrument used in this study was a DDC-8 resistivity meter.

3.2. Data analysis and synthesis

Primary data were analysed and synthesized through different laboratory procedures to provide meaningful information and conclusions. A total of five fresh bulk rock and coal samples were collected randomly from outcrops, pits and trenches across the study area. The samples were prepared in a geological survey at the Ethiopia Laboratory. The samples were first washed to remove any rock dust and fragments and then chipped to powder form for geochemical analysis. Each sample was divided into representative subsamples, which were later used for geochemical analysis.

Whole-rock samples were crushed, powdered and dissolved, and major oxide analysis was carried out via a geological survey at the Ethiopian Laboratory using atomic absorption spectrometry (AAS) after $LiBO_2$ fusion, HF attack, and gravimetric and colorimetric preparation processes.

Microsoft Excel 2016 and GCDkit 3 software were used to process geochemical data in tables and multivariant diagrams, which are very easy to interoperate. Then, all the processed data were compared with field investigations and different standards to obtain meaningful information about the classification, discrimination and petrogenesis of the rocks and minerals in the study area. Pits and trenches were logged by using starter software to obtain information about the vertical thickness and lateral continuity of the coal seam in the area. The quality of the coal deposits was measured according to the ASTM standard, which is based on calorific value, fixed carbon and volatile content.

3.3. Data interpretation

A systematic approach is used to obtain meaningful information from analysed raw data. The primary data collected from the field were interpreted and analysed in the laboratory to obtain geochemical, lithological and structural data. Based on the results of the final analysis, a justifiable conclusion from the analysis was made on the lithology and geochemistry of the area, and recommendations were made and presented in the form of texts, different data tables and geochemical graphs.

4. Geology of the study area

4.1. Lithological descriptions

The study area is covered with a variety of lithologic units. Both sedimentary and igneous rocks are found in the study area. The most dominant lithologic units in the study area are rhyolite, basalt and coal. In addition to the abovementioned rock units, non-mappable rock units such as trachyte and dolerite outcrops are apparently observed in the study area. The sedimentary units exposed in the study area are shale and coalbeds**,** but they are not mappable at the scale of 1:25,000.

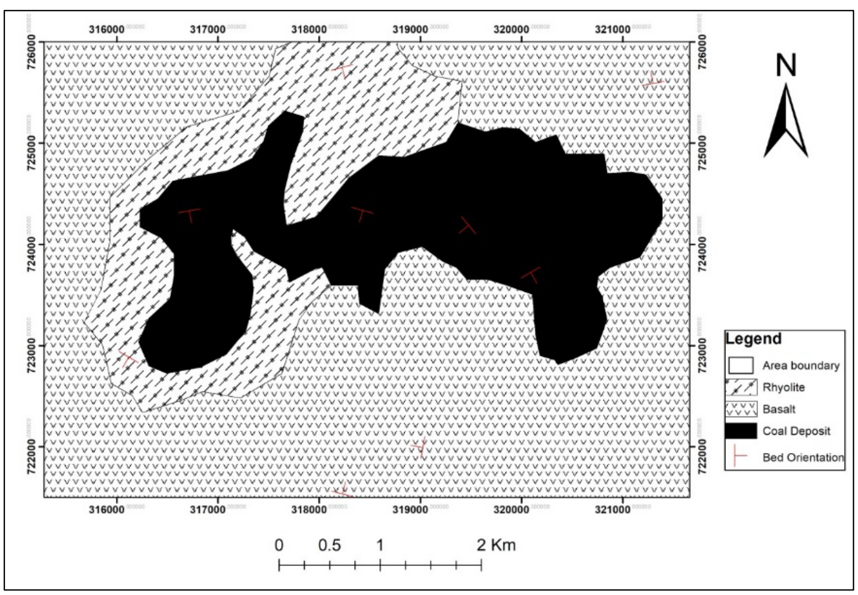


Figure 2. Geological map of the study area.

Basalt: This is the most dominant rock unit found in the study area. It has an aphanitic texture with **a** dark color due to its mafic composition. The basalt unit contacts both rhyolite and coalbeds. Mineralologically, this unit contains phenocrysts of plagioclase and olivine on the groundmasses of fine-grained plagioclase and pyroxene minerals. Adjacent to the riverbed, tilted columnar joints are found in contact with trachyte lithology. The columnar joints have hexagonal features formed due to outwards crystallization in all directions. This unit is characterized by intermediate to low silica content (35.82-53.9%), alkali content (Na_2O (0.02-2.58%)), K_2O content (0.01% - 0.6%), ferromagnesian content (Fe2O3 (9.16-20.32%)), MgO content (2.22- 9.05%), and CaO content (7.18- 9.06%) with low amounts of all other major oxides.

Rhyolite: The study area is covered with rhyolite units with considerable areal coverage. The rhyolite unit has a light reddish color and exhibits a flow banding structure. This rock unit is found to host coal seams with variable thicknesses in the sequential volcanic layering of this unit.

5. Results and discussion

5.1.Geochemical results

Representative rock samples were collected from different outcrops for geochemical analysis. Major and minor oxides were analysed via a geological survey in Ethiopia using an atomic absorption spectrometer to determine the geochemical characteristics of the rock. The range of major and minor element concentrations is expressed in wt. % in oxide (Table 1)

Table 1. Chemical composition (major oxide in wt. %) of Kucha rocks.

Sample code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K2O	MnO	P_2O5	TiO_2
K-12	47.9	14.19	9.16	9.06	8.9	1.6	0.24	0.14	0.2	0.33
K-11	47.9	14.69	12.8	8.46	9.06	1.7	<0.01	0.12	0.2	0.36
K-19	51.96	15.93	13.68	8	4.84	2.58	0.28	0.18	0.45	1.38
K-111	53.9	14.6	12.92	7.18	5.02	2.48	0.6	0.16	0.49	1.66
B-T1S5	35.82	24.32	20.32	<0.01	2.22	0.02	<0.01	0.04	0.17	1.38

In general, the geochemistry of the major and minor element concentrations of the samples analysed is expressed in wt. % of their oxides and reveals the following:

- Low SiO_2, the most abundant oxide in all the rock types, had values less than 53.9%. Al_2O_3, the second most abundant oxide in igneous rocks, ranges from 14.19-24.32%. MnO and P_2O_5 are the least abundant oxides, with an average composition ranging between 0.04% and 0.49% in all the rocks. Medium- to high-strength ferromagnesian compounds include Fe2O3 from 9.16- to 20.32%, MgO from 2.22-9.05%, and CaO from 7.18-9.06%, except for one sample (B-TS5), with a value <0.01%, TiO2 from 0.33-1.66%, Na2O from 0.02-2.58%, and low K2O from 0.01%-0.6%.

These characteristics suggest that most of the rocks are mafic in composition, indicating richer mafic and ferromagnesian minerals than felsic minerals. According to the major oxide geochemistry, the rock types are Picrobasalt to basaltic andesite.

In the Harker variation diagrams for most of the samples, MgO, Fe_2O_3 P_2O_5 TiO_2, Al_2O_3, and CaO decrease with increasing SiO_2 content, with sharp decreases and increases in MgO and K_2O, respectively, which can be a result of phase changes. SiO_2 has negative correlations with Al_2O_3 and CaO and a positive correlation with Na_2O, indicating plagioclase fractionation. Because MgO, CaO, and Fe_2O_3 take part in ferromagnesian mineral formation in the early stages of crystallization, their concentrations decrease with increasing SiO_2 content. SiO_2 shows a good positive correlation with K_2O, supporting the role of fractional crystallization.

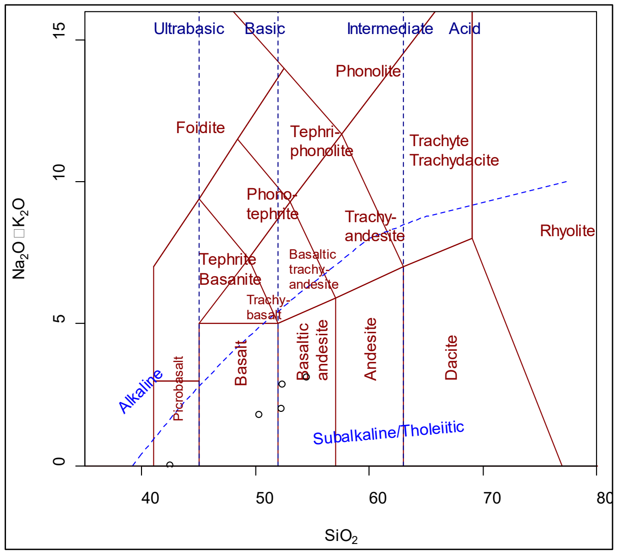


Figure 3. Total alkalis versus silica (TAS) [12] plot.

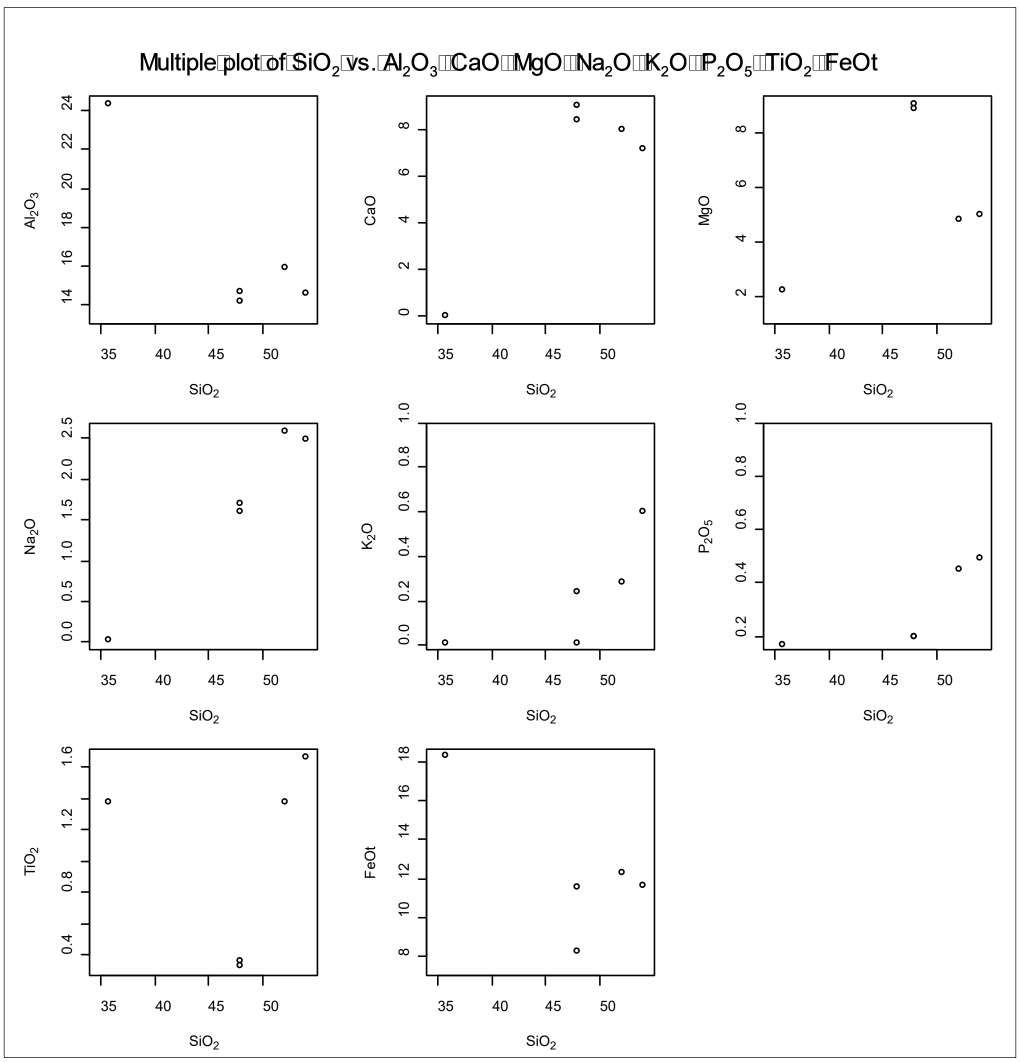


Figure 4. Multiple plots of silica versus major oxides.

Most of the samples are tholeiitic, which indicates that the rocks in the area are either products of decompression melting of mantle rocks.

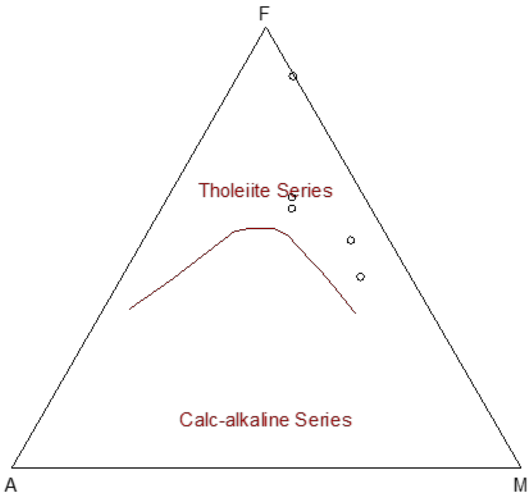


Figure 5. AFM plot [13].

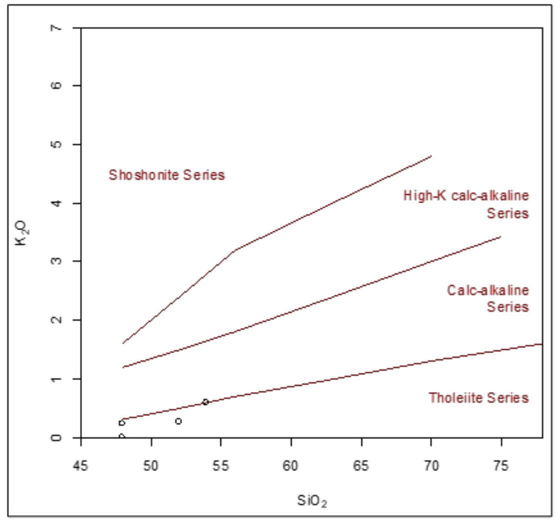


Figure 6. SiO_2-K_2O plot [14].

Based on the aluminum saturation, the samples from the study area are classified as meta-aluminous. This indicates that the rocks were formed by fractionation of mantle-derived magmas.

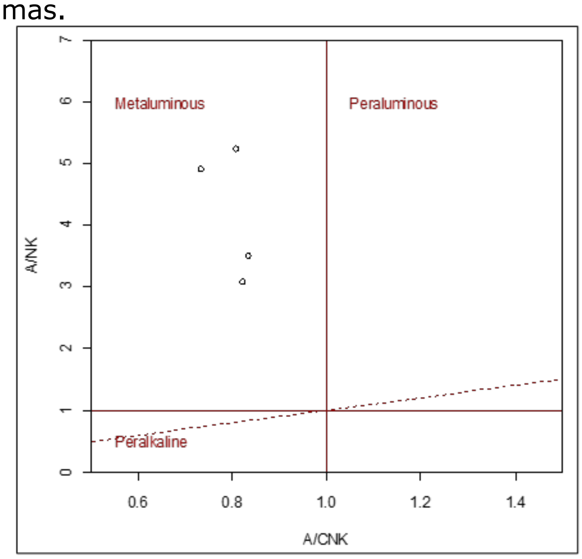


Figure 7. A/CNK – A/NK Plot [15].

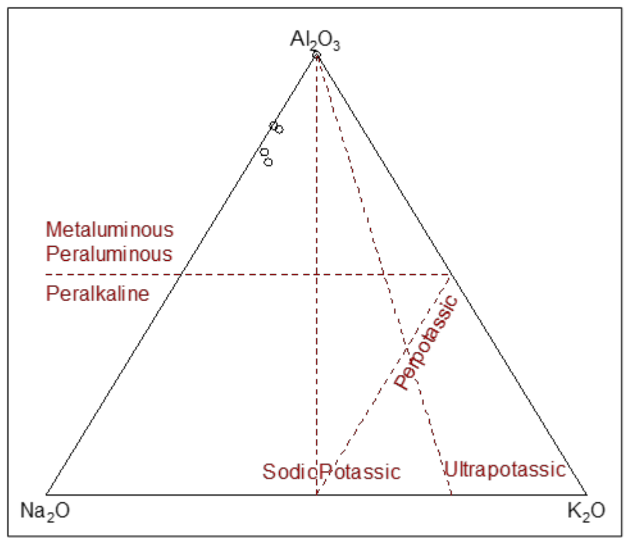


Figure 8. Molar Na_2O – Al_2O_3 – K_2O Plot.

6. Coal potential of the study area

During geological mapping, the existing outcrops are delineated, and geological structures are recorded. The geological mapping activities helped in the selection of probable coal potential sites, and representative coal samples were collected from the exposed areas. After geological mapping and analysis of the surface coal samples, detailed coal potential mapping was performed at a scale of 1:10,000. Based on geological mapping and surface coal sample analytical products, three potential coal sites are selected, and detailed mapping is performed at a scale of 1:10,000.

6.1. Coal site one

This site is characterized by the availability of coal deposits in contact with trachyte and dolerite units. In the northern part of the study area, the coal deposit contacts the rhyolite, dolerite and soil units. The southwestern part of the study area is a marshy area covered with grasses and wet soils. The eastern part of the coal site is dolerite and makes sharp contact with the coal unit. The total areal coverage of this coal bearing site is 89,456 m2 without including adjacent lithologic units.

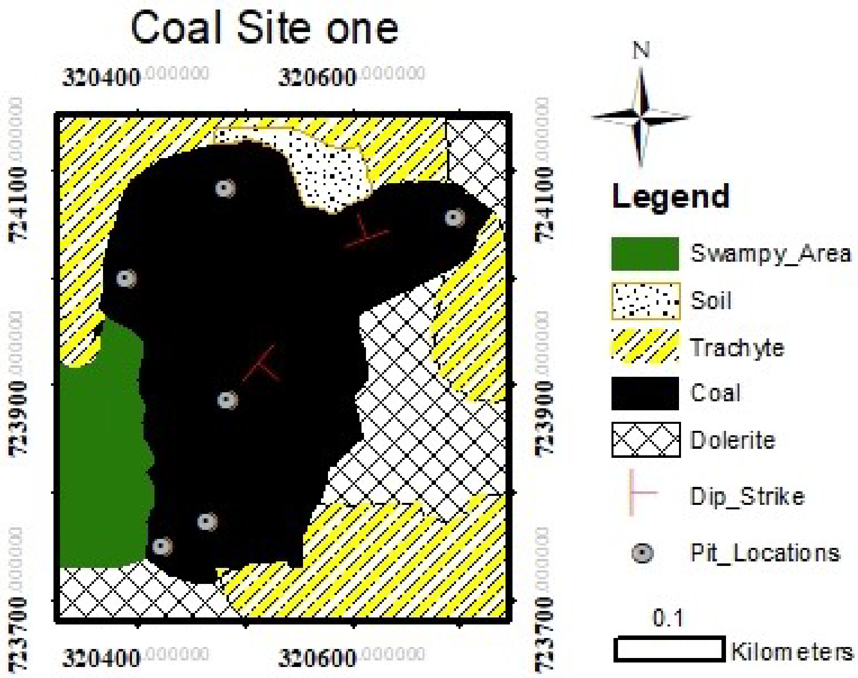


Figure 9. Coal site one.

6.2. Coal site two

The coal deposit in this area contacts rhyolite, trachyte, and basalt rock units. Most of the coal margins are bounded by basalt and dolerite basalt units. In the northern and northeastern parts of the study area, this coal unit has sharp contact with the rhyolite unit. The total areal coverage of the polygon representing the coal unit is 65,872 m^2. The structural data show that the coal seam has variable strike and dip directions, as indicated on the map in Figure 10.

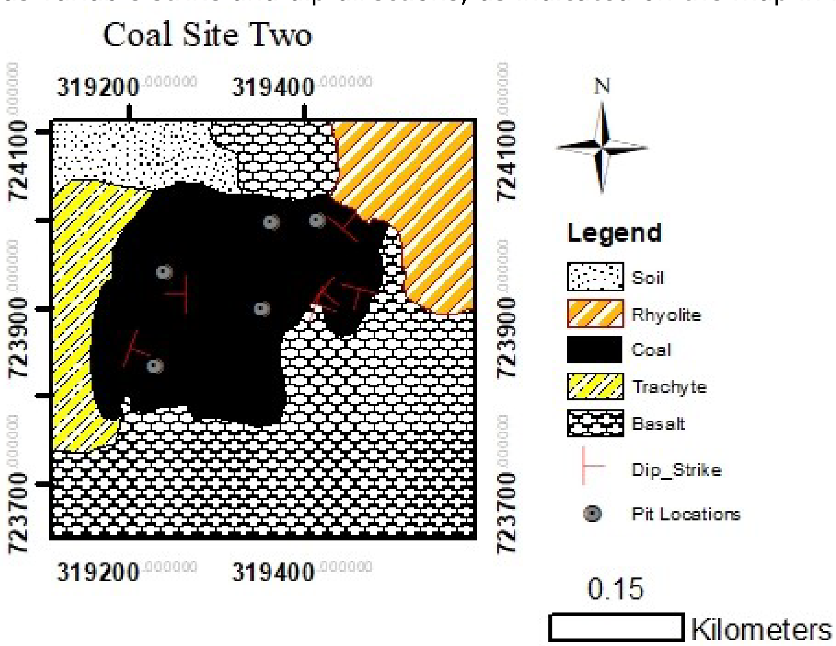


Figure 10. Coal site two.

6.3. Coal site three

This coal site is the widest coal deposit among the three localities of coal deposit horizons. The coal deposit mostly contacts the trachyte unit and, in some parts, is overlain by the soil deposit. The coal deposit strikes from the northeast to southwest directions. The total areal coverage of the coal deposit is 164,551 m2.

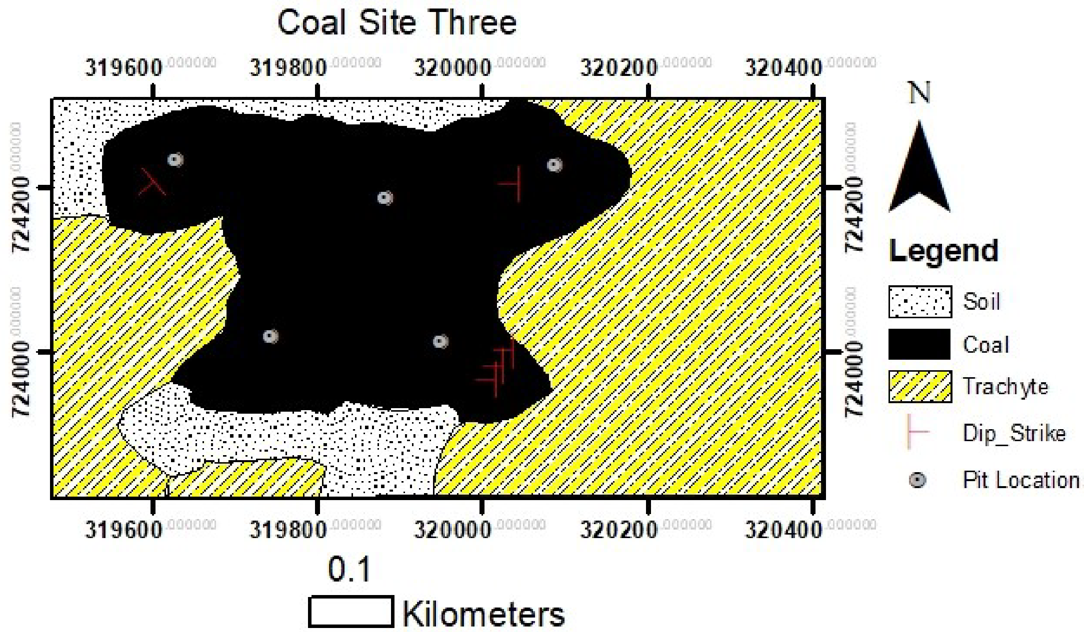


Figure 11. Coal site 3.

7. Pitting and trenching

Test pits are dug for the three delineated areas of coal occurrences, log data are recorded for the possible vertical continuity of coal deposits, and representative samples are taken for chemical analysis. Three potential coal sites are delineated via 1:10,000 mineralization mapping. Five test pits were dug for each polygon of potential coal sites. Trenching and test pits are dug by using manpower to a maximum depth of three meters. The coal thickness data are shown in Table 5. The average coal thickness of each coal polygon is computed from individual test pits.

Figure 12. Test pit.

Table 1. Coal site one log graph.

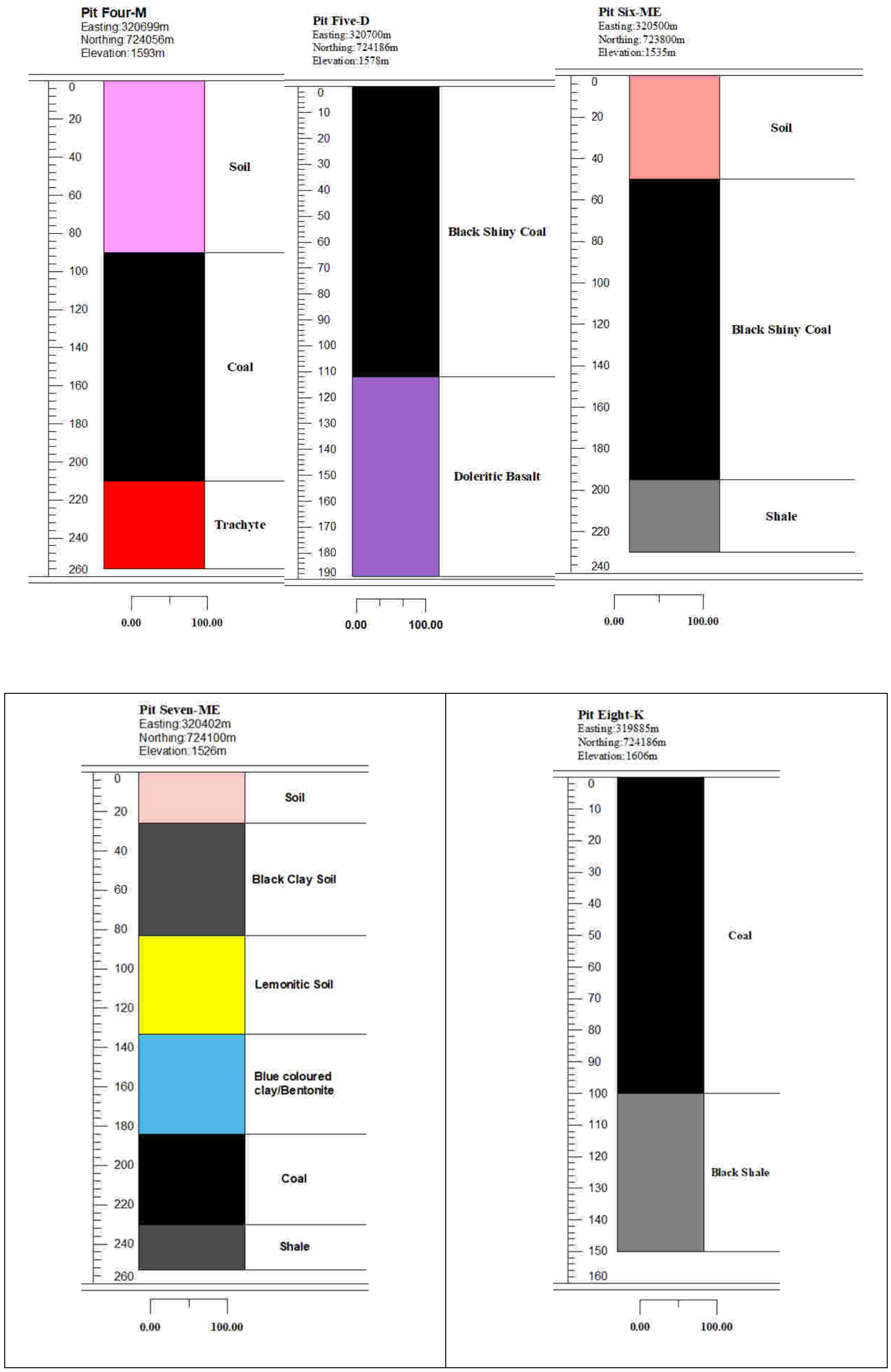


Table 2. Test Pits log graph for coal site two.

Table 3.Test pits log graph for coal site three.

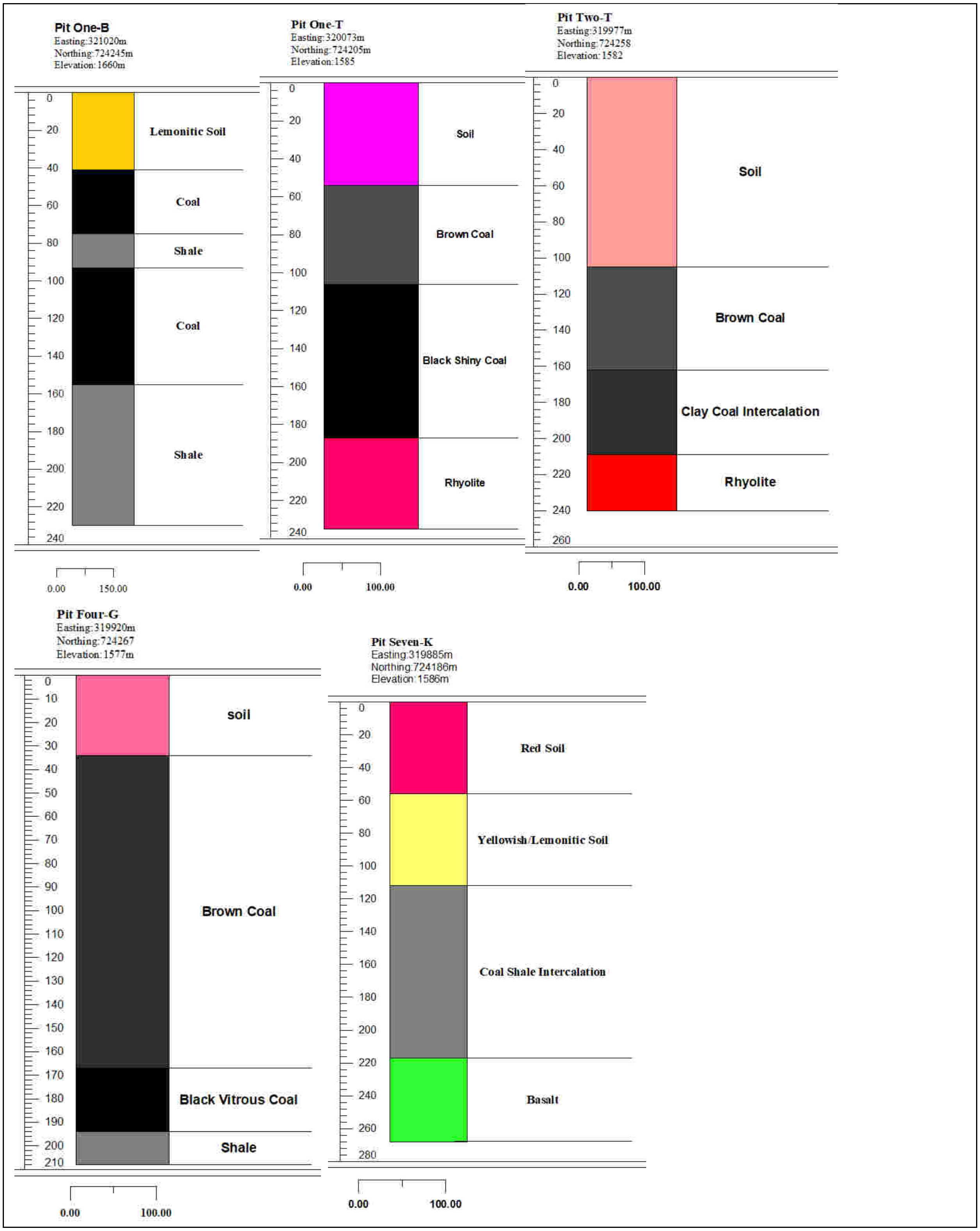


Table 4. Average thickness of the test pits

Coal Site one	Area of the coal site one				89,456.175307m^2
	Pit 4-M	Pit 5-D	Pit 6-ME	Pit 7-ME	Pit 8-Kara
Coal thickness in Cm	126	110	150	48	100
Average coal thickness in cm	**106.8**				
Coal site two	Area of the coal site two				65,872.258939m^2
	Pit 1-S	Pit 2-S	Pit 3-S	Pit 3-T	Pit 4-ME
Coal thickness in cm	120	118	116	126	50
Average coal thickness in cm	**106**				
Coal site three	Area of the coal site three				164,551.635116 m^2
	Pit 1-T	Pit 1-B	Pit 4-G	Pit 2-T	Pit 7-K
Coal thickness in cm	50	135	160	112	114
Average coal thickness in cm	**114.2**				

8. Coal reserve calculations

The amount of coal deposited on three coal sites or blocks is computed by the polygonal method, which uses the total areal coverage of each section. The third dimension is the vertical thickness or Z-axis of the coal seam, which is calculated as the average thickness from a number of test pits dug together with the thickness of the coalbed layer obtained from geophysical investigations. As stated above in Table 5, the average thicknesses of the coal deposits from the test pits are 1.068 m, 1.06 m and 1.142 m for coal site one, coal site two and coal site three, respectively.

Based on a geophysical survey of the three blocks, the average thickness of the coal layer is 2.62 m. Therefore, based on both the geophysical and test pit log data, the average thicknesses of the coal deposits are 1.844 m, 1.84 m and 1.88 m for coal sites one, two and three, respectively.

The average coal thickness computed from both test pits and geophysical surveys is used to compute the total volume of coal sites. Therefore, the area of each coal site is multiplied by its average thickness to obtain the total volume of the coal deposit. Based on this procedure, the total volumes of coal sites one, two and three are 120,229.11 m3, 121,205 m^3 and 227,081.3 m3, respectively.

Table 5. The average thickness, area and volume of the three coal sites.

Coal Site one	Area of the coal site one	89,456.175m^2
	Average coal thickness in meter	1.844 m
	Volume of coal site one	164,957.2 m^3
Coal site two	Area of the coal site two	65,872.3m^2
	Average coal thickness in meter	1.84 m
	Volume of coal site two	121,205 m^3
Coal site three	Area of the coal site three	164,551.6 m^2
	Average coal thickness in meter	1.88 m
	Volume of coal site three	309,357m^3

The proximate analysis of the coal samples and their rank characterization indicated that the coal is subbituminous. Therefore, the specific gravity of subbituminous coal is used to calculate the tonnage of coal deposits at each site.
This is an approximate reserve estimation based on the measured thickness of the coal deposits from test pits. The fifteen vertical sections were selected to delineate horizons of coal deposits. The criteria used to estimate the coal deposit reserves are based on the equation of [16]. Reserve = A*m*ρ, where 'A' is the area, 'm' is the mean thickness and 'ρ' is the density. The specific gravity of subbituminous coal is 1300 kg/m^3, which is multiplied by the total volume of each coal site to obtain the tonnage of the deposit.

Table 6. Coal reserves.

Coal site one	Volume of coal site one	164,957.2 m^3
	Density of subbituminous coal	1300Kg/m^3
	Tonnage	214,444.36t=214.444kt
Coal site two	Volume of coal site two	121,205 m^3
	Density of subbituminous coal	1300Kg/m^3
	Tonnage	127,566.5t=127.57kT
Coal site three	Volume of coal site three	309,357m^3
	Density of subbituminous coal	1300Kg/m^3
	Tonnage	402,164.1t =402.164kt
The total tonnage	Coal site 1+Coal Site 2+Coal Site 3	744,174.96t

9. Chemical analysis of coal

Coal samples collected from the surface and subsurface of the earth during mapping and test pits, respectively, were chemically analysed via proximate analysis at the Geological Survey of Ethiopia. Among the nineteen analysed coal samples, eight were taken from the surface, and the remaining eleven samples were taken from below the surface, while test pits were dug to determine the thickness and vertical continuity of the coal deposit.

Table 8. Results of chemical analysis.

Sample code	X	Y	Z	Moisture %	Volatile Matter%	Fixed carbon %	Ash%	Calorific value cal/g	Sulphur %
C-T2S1	317675	725024	1440	1.62	7.27	41.93	49.18	3308.75	0.2
C-T3S1	316556	722843	1511	3.54	8.77	1.15	86.55	ND	0.09
C-T1S6	320135	723510	1538	3.15	30.73	55.78	10.34	6873.76	0.87
C-TXSY	318183	724514	1542	2.14	30.1	23.5	44.26	4160.34	0.22
C-T1S3	318173	724501	1443	1.75	32.6	26.38	39.27	4132.85	0.16
C-T1S1	319462	724151	1546	2.56	18.08	11.28	68.08	1007.74	0.04
C-T1S4	320426	723749	1535	2.91	30.66	48.97	17.46	6233.16	0.57
C-TY2SY2	320073	724375	1532	3.37	6.53	0.04	90.06	ND	<0.02
P1S	319364	723998	1539	7.62	21.15	13.58	57.65	1470.71	0.08
P5S	319417	723999	1546	12.84	17.89	18.3	50.97	1754.91	0.03
P5D	319885	724186	1578	3.46	23.76	11.9	60.88	1492.14	0.04
P6B	319280	724137	1535	8	32.98	38.92	20.09	5412.33	0.34
P1B	321020	724245	1660	8.73	15.54	12.16	63.57	1007.24	<0.02
P8K	319885	724186	1650	2.76	25.65	16.68	54.9	2335.16	<0.02
P4ME	319354	723898	1523	5.22	30.23	42.07	22.49	5587.84	0.47
P4M	320699	724056	1593	9.01	12.09	2.07	76.83	ND	<0.02
P2T	319977	724258	1582	7.79	13.11	2.44	76.66	ND	<0.02
P4G	319920	724267	1577	2.69	25.41	16.85	55.05	2489.11	<0.02
P3T	319954	724268	1578	3.66	24.1	9.7	62.55	1370.23	<0.02

9.1. Volatile matter (VM)

VM is one of the most common parameters measured in coal. It is part of a standard proximate analysis. Volatile matter is essentially a measure of the nonwater gases formed from a coal sample during heating. It is measured as the weight percent of gas (emissions) from a coal sample that is released during heating.

VM is directly related to coal rank; as rank increases, the volatile matter content decreases [5]. The volatile matter content exhibited the opposite trend to that of the fixed carbon content with rank. As volatile matter is driven from the coal matrix with increasing rank, the relative carbon percentage tends to increase.

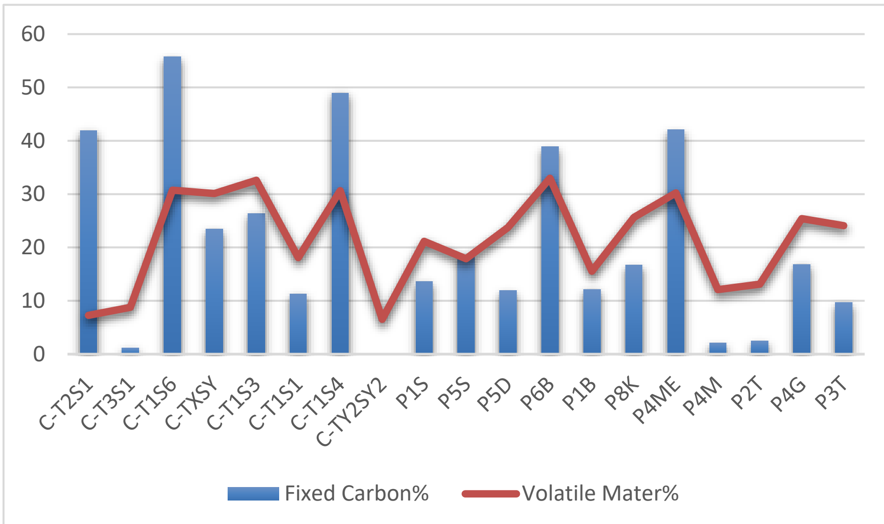


Figure 13. Fixed carbon and volatile matter relationships.

The volatile matter values of the samples collected in the study area ranged from 6.53-32.98 (Table above). Many electric utilities prefer coals within a narrow range of volatile matter (25 to 35%) for optimal flame stability in the boiler [17].

9.2. Fixed carbon (FC)

FC is a measure of the amount of nonvolatile carbon remaining in a coal sample. The FC content increases with rank and is used to define the rank above that of medium-volatile bituminous coal. Fixed carbon has the opposite trend of volatile matter (Figure 13) with increasing rank because increases in the amount of volatile matter driven off of coal increase the relative amount of carbon [5]. The fixed carbon content of the samples taken from the study area ranged from low (0.04%) to intermediate (55.78%).

9.3. Moisture

The moisture content is an important parameter in coal analysis. It is necessary to determine the calorific (heating) value and handling properties of coal. This property of coal is as important as wet mining since it may involve hydrolysis processes, and it contains different types of moisture. All the analysed samples taken in the study area ranged from very low to high (1.62-12.84) (Table 8).

9.4. Ash

Ash yield is one of the most common parameters measured in coal. The ash yield is measured to determine how much material remains (called ash residue) after coal is combusted. The ash in coal, which is the non-combustible residue left after carbon, oxygen, sulphur and water are removed during combustion, represents the bulk mineral matter. An increasing ash yield corresponds to a lower heating (calorific) value. Most steam coals used for electricity require less than 20% ash (air-dried), and less than 10% ash is required in most utility contracts. Coals with very low ash yields (less than 2%) are sometimes used to make silicon metal and as a feedstock for chemicals. The ash content of the samples in the study area ranges from 10.34 to 90.06%, and the samples can be utilized for various industrial applications.

9.5. Calorific Value (CV)

The calorific value mainly indicates the content of combustible elements(carbon and hydrogen). It is a measure of the heating ability of a coal and is needed to estimate the amount of coal needed to produce a desired amount of heat. The calorific value is a measure of the amount of energy produced from a unit weight of coal when it is combusted in oxygen [18]. The calorific value of the samples collected in the study area ranged from 1007.24 to 6873.76 cal/g.

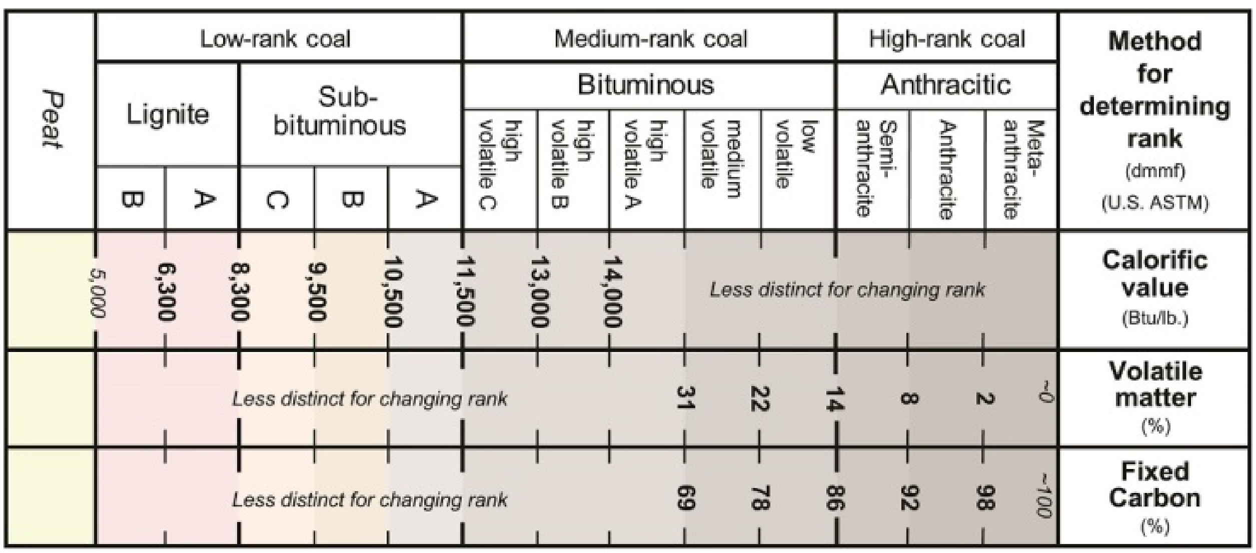
9.6. Sulphur

Sulphur is an important consideration in coal utilization. The sulphur content of all the samples ranges from very low (<0.03 to 0.87%). According to Chou (2012), coals are generally termed low sulphur (≤ 1% sulphur content), medium sulphur (≥1 to ≤ 3% sulphur content) and high sulphur (≥ 3% sulphur content). The analysed samples have very low sulphur contents.

9.7. Rank

The ASTM standard is used for determining the rank of coal, and based on the ranges of calorific value, fixed carbon content and volatile matter, the analysed coal samples range from lignite to subbituminous coal.

Table 7. ASTM standards for coal ranking.



10. Geophysical data presentation and interpretation

The electrical resistivity sounding technique was used to delineate the occurrence and extent of coal seams. Two points in the suspected coal deposit site with longitudes of 319485 m E and 319389 m E and latitudes of 724196 m N and 723934 m N were identified with the Schlumberger configuration. The vertical electrical sounding (VES) data were analysed, and the corresponding geoelectric parameters at various depths were modelled. The earth model within the study area was correlated with the available lithology of nearby pits and trenches, which is very shallow, and this limited the correlation to greater depths. The sounding signatures are HK and KQ curve types, which reveal four distinct geo-electrical equivalent layers. The dry topsoil has a resistivity range of 107–200 Ωm and an average thickness of 2 m. In the study area, a layer with a higher resistivity range (427–932Ωm) is most likely the suspected coal seam layer. Figure 18 shows that the resistivity curve below the promising coal layer has a thickness of 2.62 m and is found at a depth of 6.04 m. According to the resistivity curve in Figure 9, the probable coal layer has a thickness of 0.622 m and is found at a depth of 2.72 m. The resistivity variations of the coal layer from the two resistivity curves are most likely due to the change in the quality of the coal.

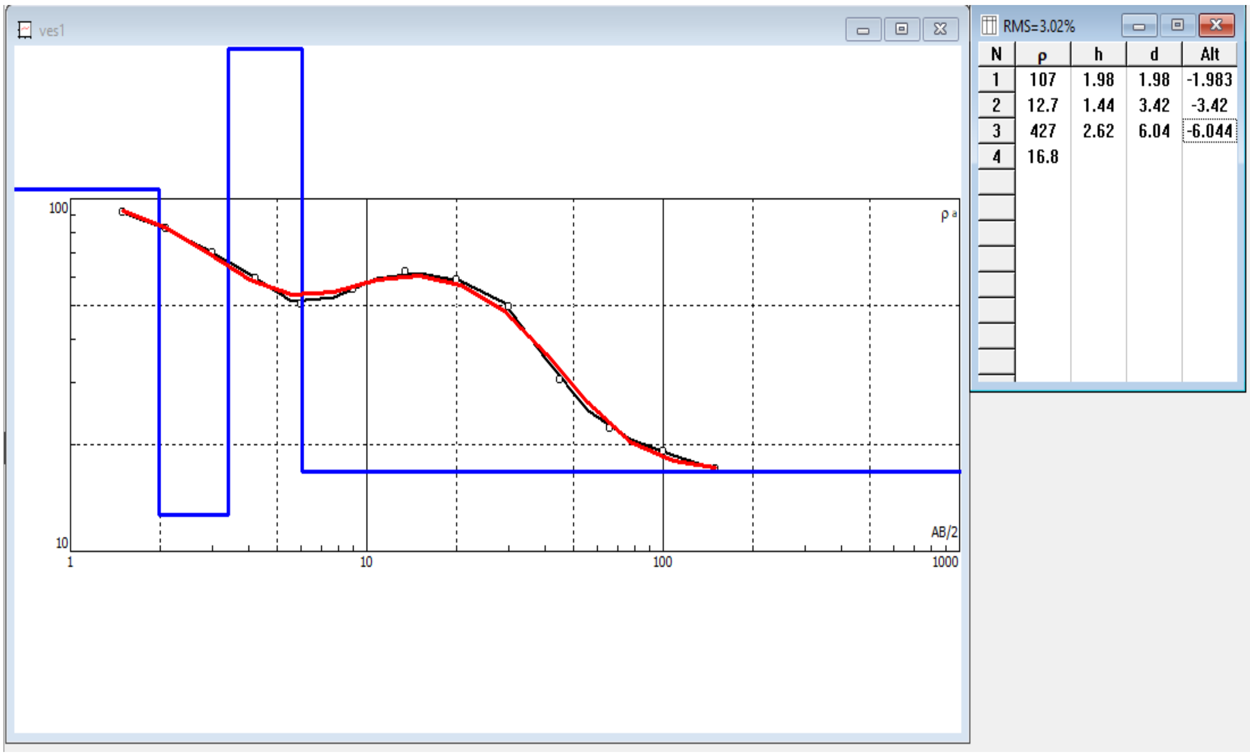


Figure 14. Resistivity curve for VES-1.

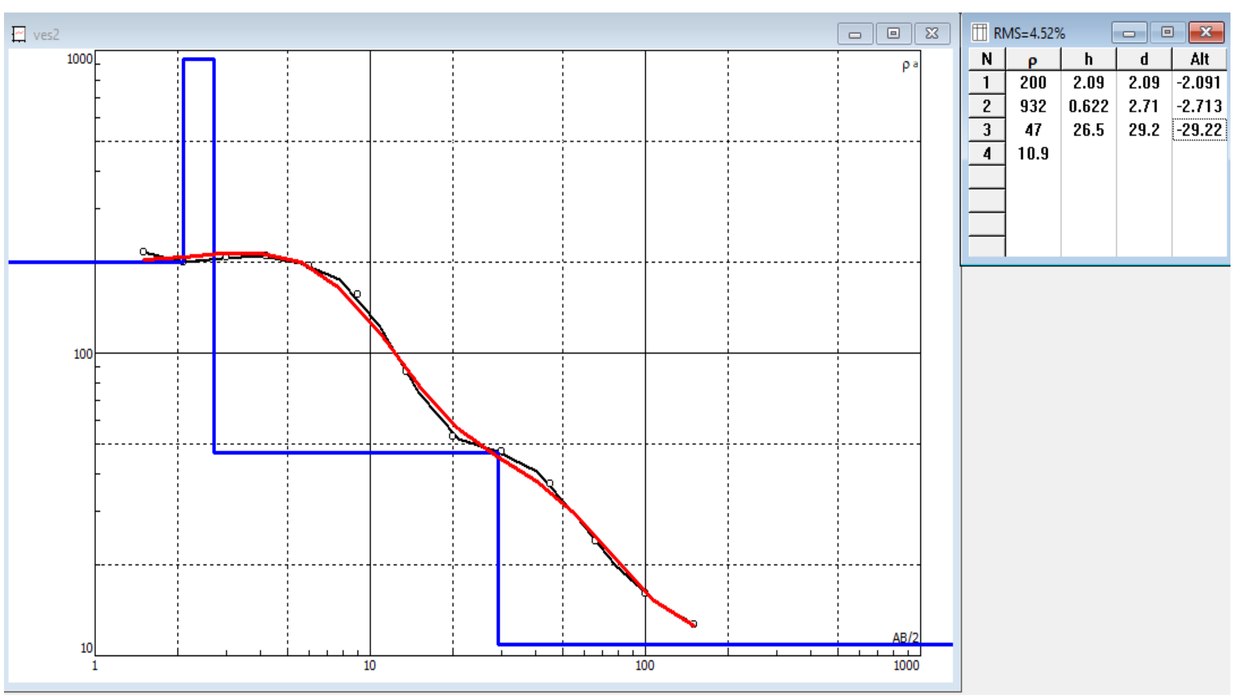


Figure 15. Resistivity curve for VES-2.

11. Conclusion

The present study was conducted in Kucha woreda with the purpose of assessing potential coal deposits. Geochemical and field investigations revealed that basalt to basaltic andesite rocks intercalated with coal seam deposits crop out in the study area. The major element geochemistry shows that the rocks in the study area are intermediate to mafic in composition and are Tholeiitic in nature, which is a product of decompression melting from a depleted source. Analysis of the coal samples revealed that the moisture content ranged from 1.62-12.84%, the volatile matter content ranged from 6.53-32.98%, the fixed carbon content ranged from 0.04-55.78%, the ash content ranged from 10.34 to 90.06%, and the calorific value ranged from 1007.24 to 6873.76 Cal/g. This indicates that, compared with the ASTM international standards, the rank of Kucha coal lies on the lignite to subbituminous.

Fifteen test pits were dug in all potential coal sites, and the average thickness of the coal seams ranged from 1.06 m to 1.14 m. From the geophysical survey of the vertical electrical sounding results, a coal layer with an average thickness ranging from 0.62 m to 2.62 m was identified. Based on the log results of pits, geophysical results and areal coverage of coal deposits, the study area is estimated to contain approximately 744,174.96 tons of coal.

Data availability statement: *All the data are included in the manuscript.*

Conflict of interest

There are no conflicts of interest associated with this paper. The authors would be fully responsible if the paper was found to violate any copyright law in the future.

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