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IN SITU SAMPLING TO DETERMINE THE VOLUMETRIC WEIGHT AND NATURAL MOISTURE OF THE COAL

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Abstract: The ongoing energy crisis highlights the urgent need to utilize coal from existing power plants for electricity generation. The exploitation of geological coal reserves in the Sibovci mine is influenced by the terrain configuration, particularly the roof and floor layers of the coal seam. This paper presents a methodology for coal sampling in the field and laboratory analysis to determine calorific value, bulk density, and natural moisture content. These parameters are crucial for ensuring both geotechnical safety and environmental protection during coal extraction and transportation. The study involved collecting 172 samples from the open coal seam profile, from an elevation range of 550 m to 650 m, using a modified drilling device. The samples were analyzed to determine the average values, variance, and distribution of bulk density and natural moisture content. Additionally, correlation analysis was conducted between the two parameters. This research helps optimize the combustion and transportation process, reducing environmental impacts such as air, water, and soil pollution. Furthermore, the findings have been applied in designing excavation slopes, contributing to improved stability and safety during coal extraction in the Sibovci mine. The study also aids in minimizing the environmental footprint of coal exploitation, ensuring that it aligns with established standards for sustainable energy production.

***Keywords*:** *coal samples, natural moisture content, bulk density, statistical correlation, coal exploitation*

1. INTRODUCTION

The territory of the Republic of Kosovo is characterized by a complex geological structure and is country rich in natural resources and subterranean wealth. One of the most

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significant underground resources found in large quantities is coal, which is located near the municipality of Obiliq. Kosovo ranks fifth globally in terms of proven lignite reserves. From a geological perspective, the lignite deposits in Kosovo are among the most favorable in Europe. The average overburden removal ratio is 1.7 m^3 per ton of coal, and the economically viable reserves represent some of the richest in Europe, ensuring electricity production for the coming decades. Kosovo's most important energy resource is coal, which accounts for approximately 97% of the total electricity production. The first coal exploration activities in Kosovo began at the start of the 20th century, when it was established that the country possesses significant coal reserves. In 1922, underground mining commenced at the Hade mine, followed by the Babush mine in Lipjan. Systematic geological research on Kosovo's coal basin began between 1952 and 1957. During this period, preparations were made to transition coal exploitation in the Kosovo basin from underground to surface mining, while also considering the potential for large-scale exploitation to meet the needs of thermal power plants for electricity generation and industrial coal processing.

The further medium-term development of lignite extraction continues in the active mining fields of Sibovci, located in the southwestern part of the Kosovo Basin, with a significant emphasis on private investments. Based on the research conducted so far and the status of the energy mineral resource reserves, the Republic of Kosovo possesses substantial reserves of lignite coal, as outlined in references (*Mining Strategy*… 2011; Ahmeti H., Ahmeti A., and Behrami 2022; Hysen et al. 2023) presented in Table 1.

Table 1. Coal Reserves in the Republic of Kosovo

Coal-bearing basins	Reserves [t]		
	geological	balance	non-balance
Kosovo	10,091,000,000	8,772,000,000	1,319,000,000
Dukagjini	2,244,830,000	2,047,700,000	197,130,000
Drenica	106,631,000	73,188,000	33,443,000
$\sum =$	12,442,461,000	10,892,888,000	1,549,573,000

2. STUDY AREA

The study area of the coal mine is located six kilometers from Pristina, as shown in Fig. 2. The slopes of these hills extend at an angle of 4 to 10 degrees, with a general decline in the direction from the southeast to the southwest, according to Hysen et al. 2023) and Elezaj (2012). From a hydrological perspective, surface waters are considered those originating from precipitation and springs, which, due to the opening of working faces, have infiltrated into the coal layers. The area encompassing the coal exploitation field is approximately 300 hectares, controlled by a network of channels. The springs created in this area result from the infiltration of surface waters into the yellow clay layers, which contain fine sands and, in some places, fossils. These clays are considered water collectors; however, beneath them are marl clays of a greyish color, which are more resistant to water, and the possibility of water movement through them is minimal under normal conditions. However, recent drilling has revealed that these clays are characterized by numerous fractures with varying angles and directions, which can create hydraulic connections between them, transforming this area into a zone of weak temporary water collection. This phenomenon becomes more pronounced in cases of severe and prolonged droughts, affecting these layers, particularly at the open faces, with a fracture system that enables the unimpeded circulation of water through these fractures, especially when followed by intense rainfall. This allows water to infiltrate until these clays become saturated and begin to swell, effectively sealing the fractures. Through these fractures, a portion of the infiltrated water enters the coal seam series, where mining activities are ongoing and drains toward lower levels. Nevertheless, based on research data to determine the most accurate values for bulk density and moisture content in the coal layers at open-pit mines, it is possible to define the geometry of the working slopes. These slopes must comply with safety factors to create favorable conditions for extracting coal in tons per cubic meter. This is in line with the requirements of the Kosovo Energy Corporation for supplying thermal power plants, which produce electricity for Kosovo's population and beyond.

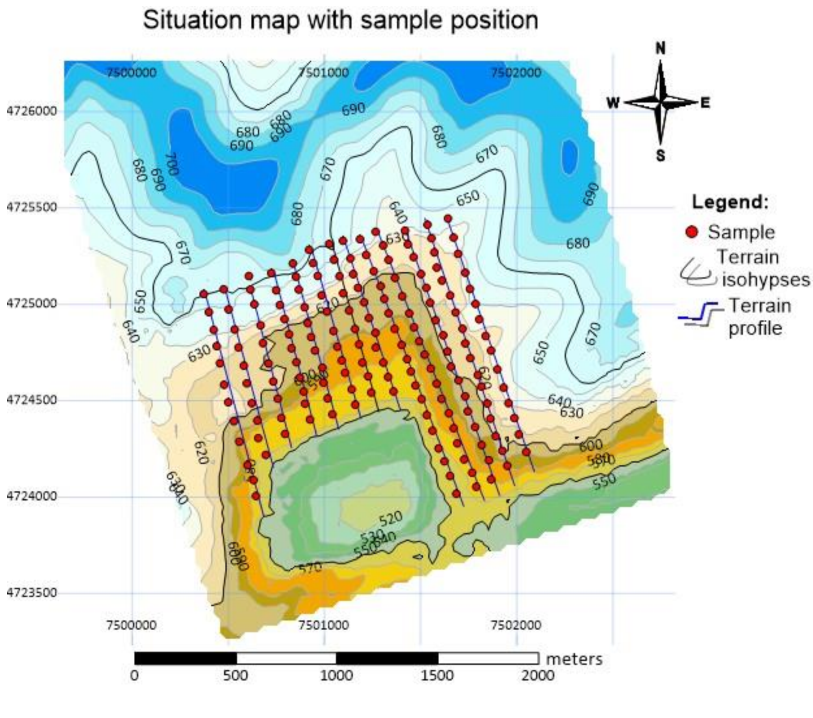

Fig. 1. Mine situation map with sample position M_1–M_{127}

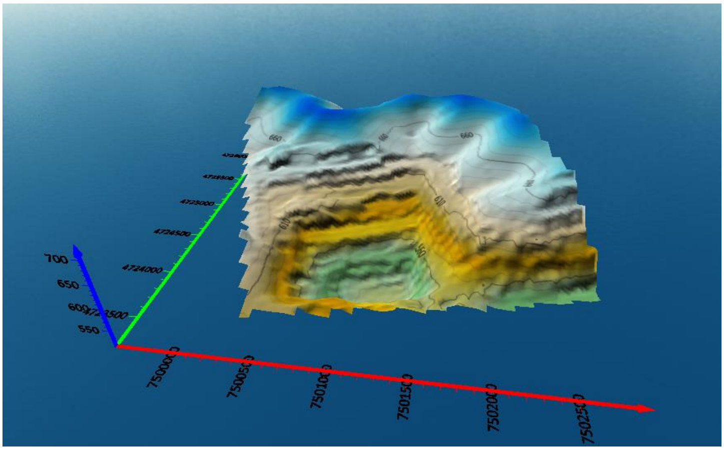

Fig. 2. 3D representation of the surface mine where coal is exploited

As a part of the importance of determining bulk density and moisture content (Krasniqi, Kadru, and Ahmeti H. 2017; Krasniqi 2020; Selvamuthu and Das 2018) indicate that this study involved the collection of 172 undisturbed samples from the coal benches in the open-pit mines. The samples were labeled M1 to M172 and are shown on the situational map presented in Fig. 1, where the sample numbers from each open bench are indicated, along with the stratigraphic levels of the coal layers and their sampling intervals. Based on the situational map (Fig. 1), 13 profiles have been drawn, which are presented in Fig. 1. The 3D position of the coal mine is shown in Fig. 2 (Ahmeti H. and Maliqi 2023). Each sample taken was accompanied by a label indicating the sample number, profile name, coordinates, level, lithological content, and the date the sample was collected, as shown in Fig. 4.

3. GEOLOGICAL FORMATION OF THE SURFACE COAL MINE AREA

In the coal basin of Kosovo, alongside the Tertiary sediments, Quaternary sediments have also developed. The expansive area of Sibovci, located in the southwestern part of the coal basin, stretches across the northern part of the coal basin, near the town of Kastriot in the north, the Drenica River, and the village of Lismir in the south. In this region, within the Tertiary sediment series, the following lithological members are present, similar to the overall composition of the coal basin of Kosovo:

- the substratum coal series;
- the coal series;
- the overlying coal series.

Substratum series. Directly in contact with the coal series is a layer of green clay, which contains fine sand particles with carbonate concretions. In some places, there are significant concentrations of sand that appear in the form of lenses. Alongside these lithological members, this series also includes interbeds of compact clay and conglomerates (Elezaj 2012).

Coal series. Based on geological research, the average thickness of the coal layer is 59.5 m, with a maximum thickness of 93.1 m. It lies directly above the substratum series and exhibits variable thickness and heterogeneous composition. The coal series is composed of xylite, coal soil, clayey coal, and intercalations of powdered materials. these structures form the xylite and coal masses, created from fine plant remains – coal soil, clayey coal, etc. The powdered mass is composed of clay components. The coal parts of the coal series as it transitions into green clay. This coal series corresponds to Additionally, there are occurrences of coal clay, which typically appear in the lower

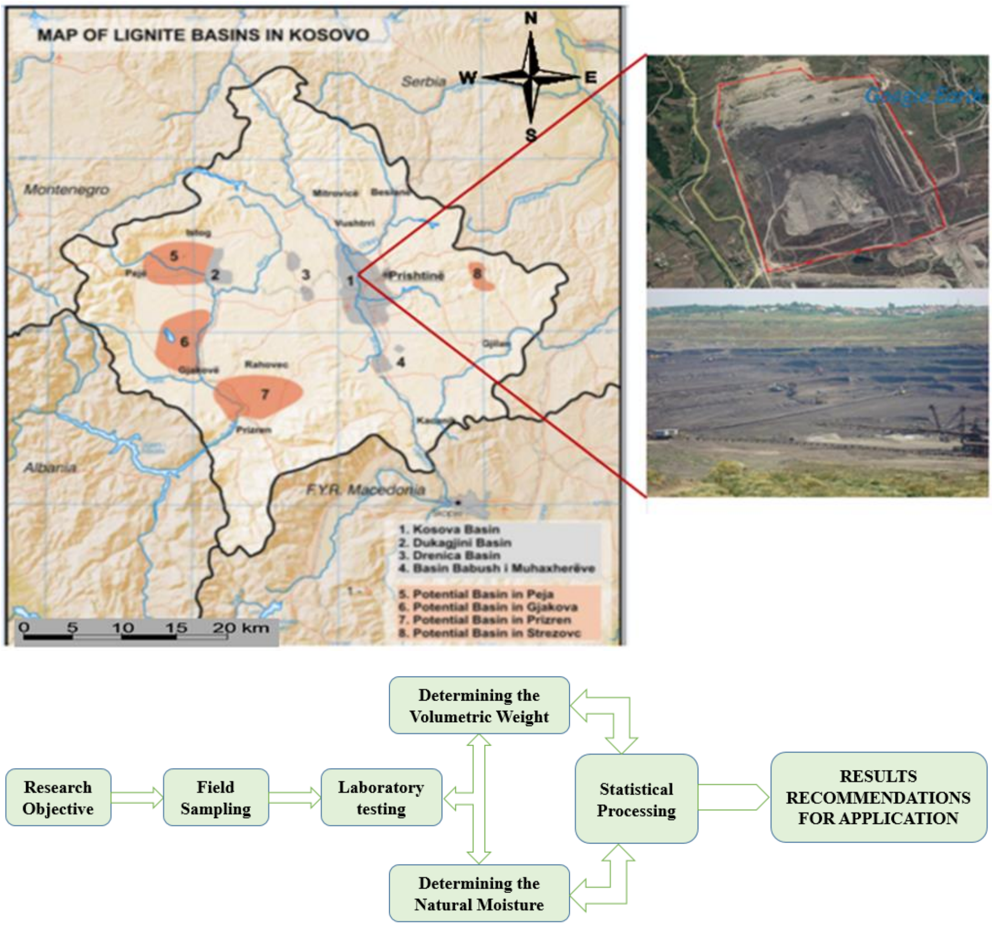

Fig. 3. Study area in the Kastriot mine (Obiliq), Prishtina.
Research flowchart

typical lignite. In its structure, well-preserved woody structures are distinguished, and series' structure features intercalations of these materials. The xylitic mass predominates in the upper part of the coal series, compared to coal soil, powdered mass, and clayey coal. Coal soil, clayey coal, and coal clay dominate the lower portion of the series. When exposed to air, coal quickly loses moisture, adopts a fine woody structure, and, over time, transitions into powdered coal, which is dark black in color. The color of the coal series varies from black to light gray to dark black. Unlike the substratum series, the overlying coal series has a sharp and distinct boundary separating the two series.

Overlying coal series. This series is composed of several lithological members. The gray clay is a homogeneous mass that exhibits notable lithological changes in vertical sections. It is relatively firm and lacks clear stratification. The gray clay is distinguished by its pale gray color and the presence of fossils, which typically appear in the area near the contact with the coal series, often in the form of shell layers. Due to atmospheric influences, the gray clay is enriched with iron and manganese oxides, as well as $CaCO_3$, transforming it into yellow clay with a thickness of 10 to 15 meters. according to Fig. 3. This clay is directly influenced by atmospheric conditions. It is quite rich in fossils and carbonate fragments. In most cases, it is covered by a humus layer, which, under current exploitation conditions, is absent according to (Hajra, Avdullahi, and Fejza 2009; Peci 2012).

4. METHODS

Field samples were collected at intervals of 100 meters along vertical profiles, with their locations depicted on the situational map in Fig. 1, using coordinates (*x*, *y*) according to the Kosovo coordinate system. The sampling process commenced at an elevation of 550 meters and continued up to 650 meters. All collected samples were

Fig. 4. In-situ sampling procedure on coal cascades

placed in plastic bags and sealed hermetically to preserve their physical and mechanical properties until further analysis. Subsequently, photographs of the samples were taken with the corresponding labels, and tags were affixed with the necessary information, including the sampling location, field coordinates, and lithological description.The samples were promptly sent to the laboratory to determine the bulk density (γ) [kN/m³] and natural moisture content (w) [%], as shown in Fig. 8. For this purpose, an electric rotary drilling machine with a rotation diameter of ϕ = 101/90 [mm] was used, as illustrated in Fig. 4. A total of 13 profiles were extracted from the situational map, as shown in Figs. 5 and 6.

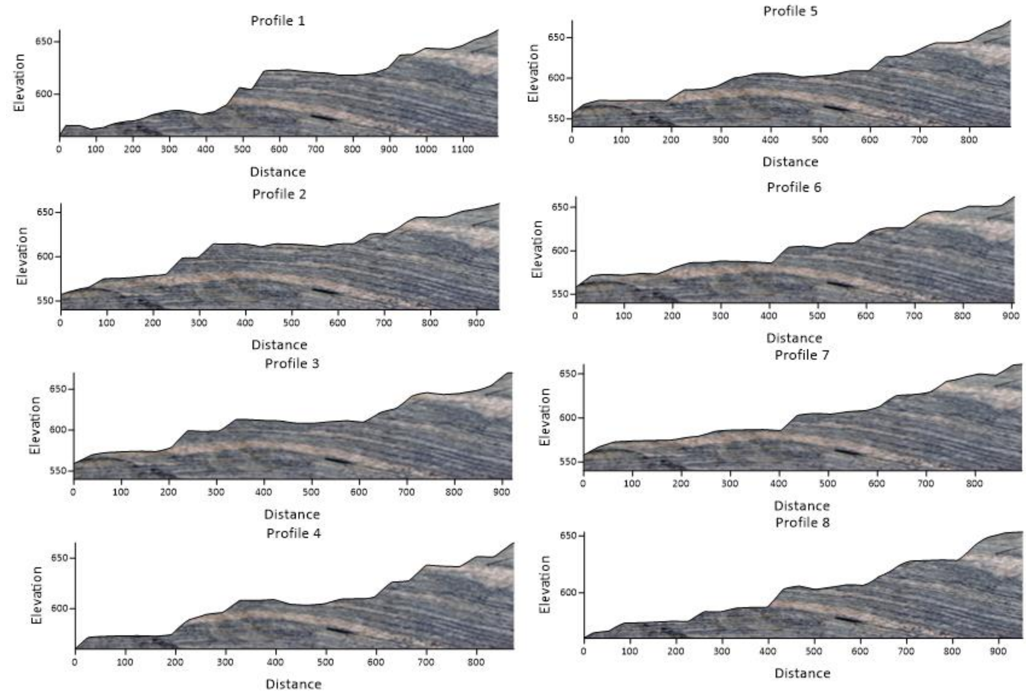

Fig. 5. Longitudinal sampling profile 1–8

All samples were collected using the rotary drilling method, without the use of water during drilling, in accordance with the technical standards of the laboratory equipment. This process was carried out in consultation with the geomechanics laboratory at the INKOS Institute, as shown in Fig. 7. Sample analysis was performed following the methodology outlined in Fig. 8. For the collection of samples with a specific diameter, the established standards and procedures for laboratory equipment were adhered to, as documented in the referenced literature (Ahmeti H., Maliqi 2023; Kadriu, Krasniqi, and Ahmeti

H. 2017).

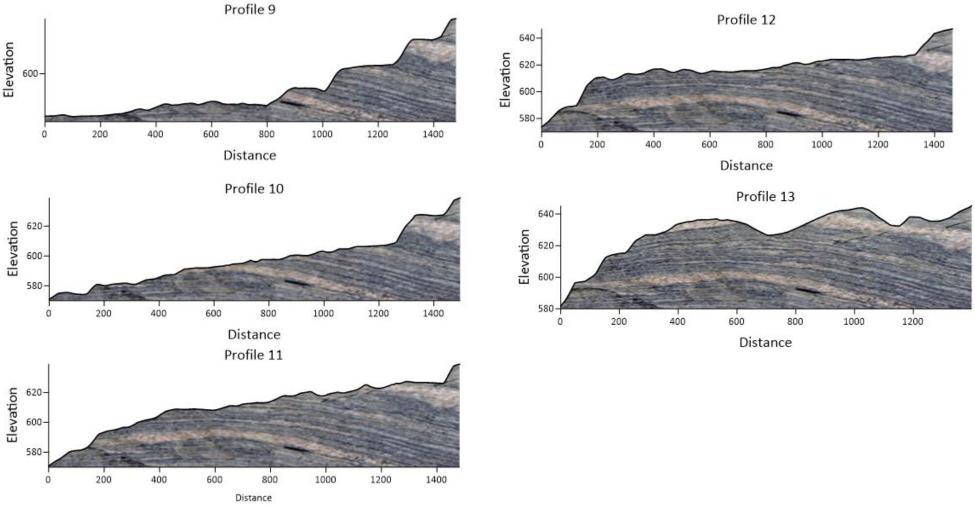

Fig. 6. Longitudinal sampling profile 9–13

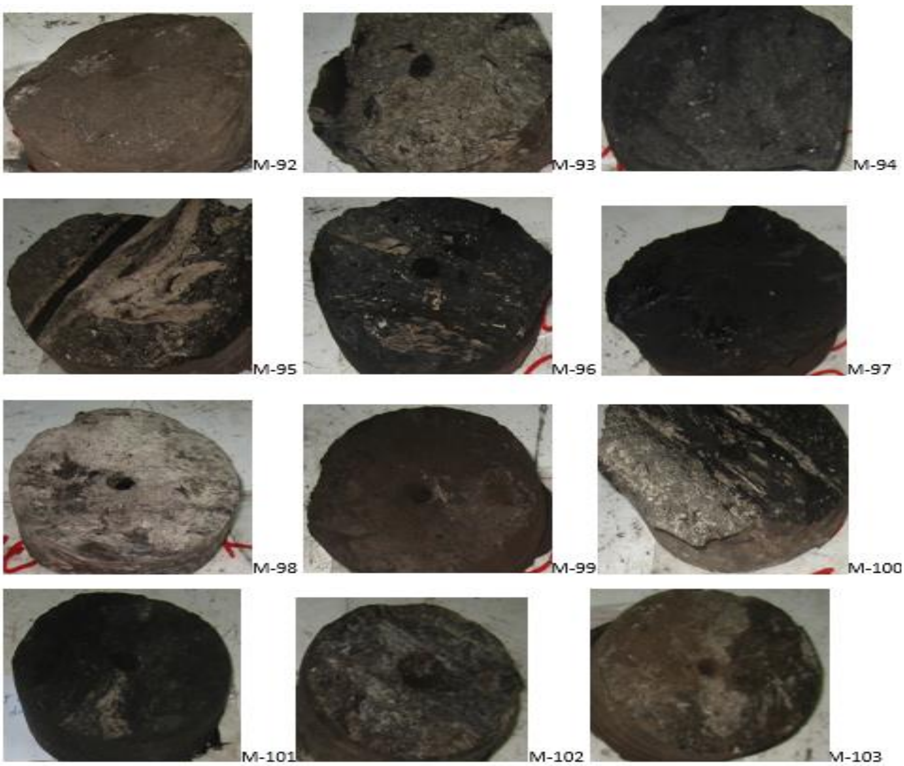

Fig. 7. Photos of samples brought to the laboratory for extraction of parameters

Fig. 8. Determination of volumetric weight with paraffin

4. RESULTS AND DISCUSSION

4.1. DETERMINATION OF PARAMETERS IN THE LABORATORY

The determination of the natural moisture content was carried out in accordance with the relevant Italian standards (CNR). The samples were dried at a temperature of 105 °C until a constant weight was achieved between two successive measurements. The change in weight between these measurements provided the amount of water present in the sample. The results were obtained based on Eqs. (1) and (2), as referenced in (Krasniqi, Kadru, and Ahmeti H. 2017; Selvamuthu and Das 2018; Das and Sobhan 2022; Smith 2014; Budhu 2010).

$$W = \frac{G_1 - G_2}{G_2 - G} 100\%, \tag{1}$$

where:

- G_1 – weight of container with material with natural moisture in [g],
- G_2 – weight of container with dried material in [g],
- G – container weight in [g],
- W – moisture content in [%].

$$\gamma_d = \frac{\gamma}{1 + w}. \tag{2}$$

The results obtained according to the work progress for the sample M_1–M_{10} are presented in Table 1, while the results according to the geological description and the number of samples are presented in Table 3.

The determination of the volumetric weight γ of coal formations with natural moisture is determined by the paraffin method according to the standard CNR BU n. 62/78. The sample with broken structure and natural moisture is given a regular geometric shape and then weighed P. Sample volume should not be less than 30 cm^3. It is immersed for 1 to 2 seconds, several times in a porcelain container with molten paraffin at a temperature of 57–60 °C, until a paraffin layer is formed on the surface of the sample with a thickness not exceeding 1.00 mm, then the sample P_1 is weighed. Knowing the density of paraffin δ_p = 0.892 kg/m^3, based on Eqs. (3) and (4) given below the volume of paraffin and the volumetric weight of coal is determined (Kadriu, Krasniqi, and Ahmeti H. 2017; Rozanski, Konior, and Balcarczyk 2019).

$$V_p = \frac{P_1 - P}{\delta_p}. \tag{3}$$

Tie the paraffin sample with a thread and immerse it in a container of water and then weigh P_2 according to Fig. 8.

$$\gamma = \frac{\gamma_u \delta_p P}{\delta_p (P_1 - P_2) - (P_1 - P)\gamma_u} \left[\frac{\text{g}}{\text{cm}^3}\right], \tag{4}$$

where:

γ_u – the density of distilled water, 1.0 [g/cm^3],
P – weight of the sample [g],
P_1 – weight of the sample with paraffin [g],
δ_p = 0.892 – the density of paraffin [g/cm^3],
P_2 – the paraffin-impregnated sample submerged in water.

The determination of volumetric weight for each sample was performed through not less than two parallel tests with the difference not being greater than 0.03%. The results obtained according to the procedure M_1–M_{10} are presented in Table 2 by applying Eqs. (3) and (4), while the ratio of moisture to volumetric weight are presented according to the diagram given in Fig. 9.

4.2. STATISTICAL PROCESSING OF SAMPLES

Sampling in the coal mine, where coal is currently being exploited, covered an area of approximately 745,108.08 m^2. During this process, a significant number of samples were analyzed in the geomechanics laboratory. The samples were collected from the field at open profiles, based on the predetermined coordinates (*x*, *y*, *z*), as shown in the situational map from (Golden Software 2022), to ensure accurate extraction and provide reliable results for geotechnical assessments. Physical parameters such as bulk density and natural moisture content of the coal were calculated through statistical processing of the collected data (*Mining Strategy* 2011; Ahmeti H., Ahmeti A., and Behrami 2022; Hysen et al. 2023), according to the specified Eqs. (5)–(8). These analyses confirmed a strong correlation between the bulk density of coal and its moisture content, which is crucial for assessing the stability of slopes and the exploitation process. This correlation is visually represented in Figs. 9–12, demonstrating the impact of changes in moisture content and bulk density to achieve greater accuracy in calculating coal reserves and advancing extraction [15]. The statistical processing of the data is a critical component of this study, as it enables the accurate evaluation of the necessary parameters for planning and optimizing coal exploitation in accordance with market demands and geotechnical standards (Heumann and Schomaker 2016; Anderson, Sweeney, and Williams 2003; Heumann, Schomaker, and Shalabh 2017; Almadhoun 2017; HEIBERGER and Holland 2015). This statistical process is also essential to ensure that the collected data are valid and can be used to improve efficiency in electricity generation, taking into account potential variations in moisture content and bulk density during different periods of exploitation.

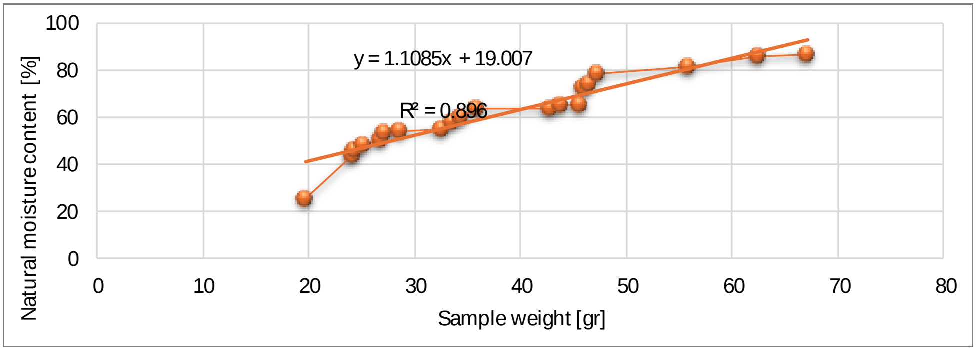

Fig. 9. Correlation diagram of volumetric weight with natural moisture

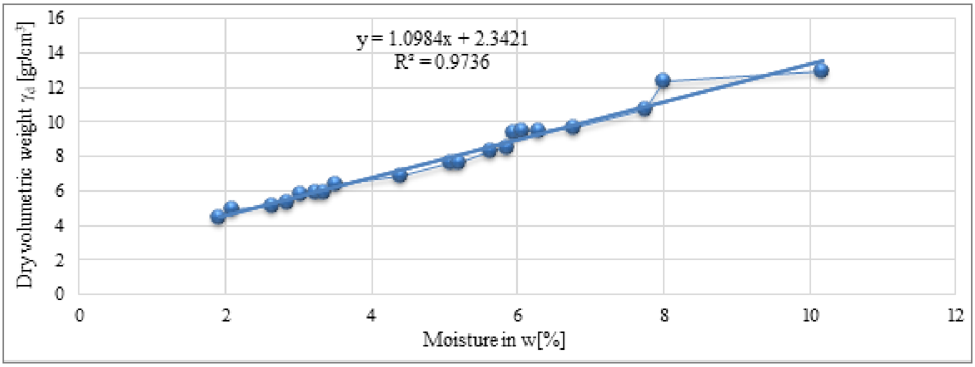

Fig. 10. Correlation diagram of dry volumetric weight with natural moisture content

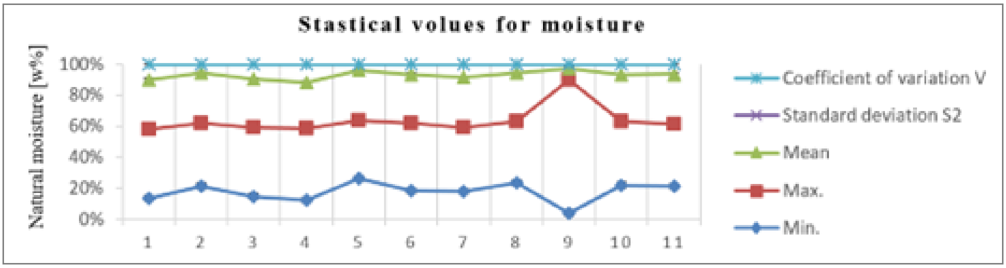

Fig. 11. Coefficient of variation and standard deviation for the natural moisture content of coal

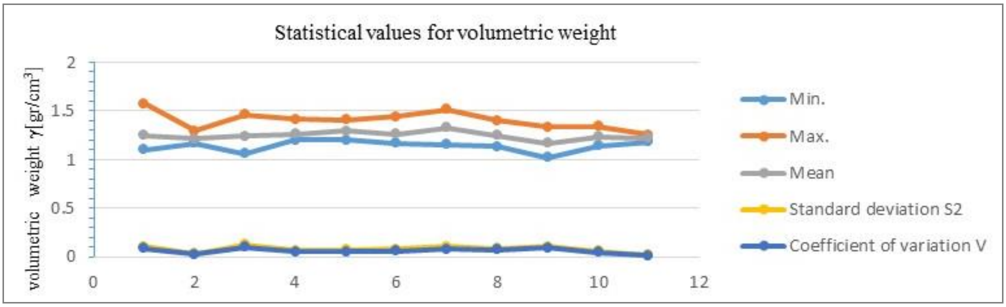

Fig. 12. Coefficient of variation and standard deviation for volumetric weight

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{N} x_i, \tag{5}$$

where N – number of samples, x_i – parameter value.

$$S^2 = \frac{1}{(n-1)}\sum_{i=1}^{N}(x_i - \bar{x})^2, \tag{6}$$

$$V = \frac{S}{\bar{X}}, \tag{7}$$

$$r = \frac{\Sigma(X_i - \bar{X})\,(Y_i - \bar{Y})}{\sqrt{\Sigma(X_i - \bar{X})^2\ \Sigma(Y_i - \bar{Y})^2}}. \tag{8}$$

4.3. CALCULATION OF SIMPLE HARMONIC MEAN

The simple harmonic mean, as defined by Eqs. (5)–(8), is employed for statistical processing between lithological layers, accounting for the fluctuation of characteristic values observed in the tests, as specified in Eqs. (9)–(11).

$$M_{thh} = \frac{N}{\Sigma \frac{1}{x_i}}, \tag{9}$$

where N – number of samples, x_i – parameter value.

$$W_{mhp} = \frac{\Sigma f}{\Sigma \frac{f}{x_i}}, \tag{10}$$

$$\gamma_{mhp} = \frac{\Sigma f}{\Sigma \frac{f}{x_i}}, \tag{11}$$

where f – number of samples, x_i – simple harmonic mean in the frame of division within the coal series obtained from Table 3 for natural moisture and from Table 4 for volumetric weight.

4.4. CONCLUSIONS ON THE PRESENTED RESULTS

In general, the exploitation of coal in existing mines is critical and heavily relies on the volumetric weight of the coal in its natural state, as well as its moisture content, both of which directly influence electricity production. Therefore, it is imperative that the values obtained for these parameters, which are used in calculations for the annual coal production and stability assessments, are precise and based on projects developed in the 1970s. However, in light of the increasing demand for electricity production for existing power plants and the general community, it is necessary to enhance coal exploitation methods to address supply shortages and meet new research requirements aimed at increasing electricity production. In this context, the reliance on geomechanical parameter data obtained from the field for 172 samples, according to the design requirements for the new mine, is essential. The sample collection points were determined in accordance with the Situation Map (Fig. 1), and actual values for the volumetric weight of the coal and its moisture content were derived in the geomechanics laboratory. For this purpose, statistical data processing was applied, as presented in Tables 3 and 4. The obtained values for coal's volumetric weight and moisture content are crucial for calculating the stability of slopes on the working front, where slope height and angle can be determined with safety factors according to geotechnical standards. Furthermore, coal extraction from excavators in the unit [t/m^3] and its exploitation will be conducted in accordance with market requirements for electricity production. The samples brought to the laboratory by the Geology sector, with their physical state, were opened and photographed. Subsequently, they were processed, and the necessary tests were conducted to assess moisture content and volumetric weight. To achieve the most accurate results for each sample, two parallel tests were performed. When the measurement results differed by more than 3% between the parallel tests, the test was repeated to ensure measurement accuracy. Statistical data processing was conducted using two primary methods: the arithmetic mean for each lithological member of the coal series, as presented in Tables 3 and 4, and the harmonic mean for the entire coal series, for the required parameters. Based on the results presented, it can be observed that the natural moisture content exceeds 45%, as indicated in Table 1, which positively contributes to reducing environmental pollution for the community. This process is significant because the coal transport from the extraction site to the existing power plants, such as Kosovo A and Kosovo B, is done via conveyor belts over a distance of approximately 4 km. From the obtained geomechanical parameter results, it can be concluded that coal reserve calculations and their exploitation will be carried out in accordance with geotechnical regulations and standards, considering the labor market requirements. These calculations will enable the creation of the geometry of side slopes and the determination of safety factors according to Eurocode EC-7 and EC-8, ensuring safety during mining activities and protecting workers and technological equipment.

5. CONCLUSIONS ABOUT THE OBTAINED RESULTS

Table 5. Results from the weighted simple harmonic mean value

Natural moisture of coal w	w_{mhp} = 52.57%
Volumetric weight of coal γ	γ_{mhp} = 1.237 g/cm^3, or 12.130 kN/m^3

CONFLICT OF INTERESTS

The authors declare no conflict of interests.

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