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Klias Peat Soil: A Depth-Based Property Assessment

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ABSTRACT

Peat soil is crucial in Southeast Asia, particularly in Sabah, where it exhibits high water content, low density, and significant organic matter. This research investigates the unique engineering behavior and characteristics of Klias tropical peat, focusing on index properties such as fiber content, organic content, and natural water content compared to other Malaysian regions. Key objectives include studying the physical properties, decomposition levels, and in-situ density of peat with depth, as well as examining its chemical composition. Results indicate distinct variations in peat density and composition at different depths, with average moisture content at 258%, organic content at 91%, fiber content at 75%, pH at 3.7, and specific gravity at 0.748. The degree of decomposition is classified as H5-H6. Findings reveal that peat density increases with depth, while sulfur remains constant (0.1% to 3.4%), oxygen decreases (28% to 24%), and carbon increases (60% to 76%) with depth. This study also explores the application of Peat Sampler in understanding the engineering behavior and characteristics of peat.

1. Introduction

The growth of development is rapidly increasing throughout the year worldwide. In Malaysia peat soil approximately covers 2.76 million hectares of which 796,782 hectares are in Peninsular Malaysia [1], 200,600 hectares in Sabah [2] and 1,765,547 hectares in Sarawak [3]. Thus, in Malaysia region, peat soils usually found in Klang Port, Johor, Melaka, Alor Setar Sabah, Sarawak and some port east coast area. In Sabah, tropical peat differs from temperate peat due to differences in climate and the plant species that decomposed to form the peat layer.

This type of soil is characterized by low shear strength, high moisture content and high compressibility which is the biggest enemy of the stabilisation of the soil. Moreover, peat soil considered as problematic soil because have very low capability in agriculture development [4]. Peat soil also not suitable for any construction such as highway, building or any construction due to its

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physical and chemical properties. Furthermore, this type of soil with little economic and utilization of this soil quite low while the demand of land for development was increasing. Therefore, it very important to find another solution to improve the stabilisation and strength for this problematic soil due to development are very limited. Any construction is very high challenging to be conducted in this area as the bearing capacity of the soil is not achieved to the certain level to support the foundation of building constructed. Thus, several construction ground improvements that can be applied in peat to enhance the strength and stiffness in soil [5].

Peat soils are the most dominant type of organic soils developed through centuries under wetland conditions by the accumulation of partially decomposed and undecomposed plant residues [6]. In Northern Asia, most common problem facing by the construction works is the soft soil or peat soil that are widely spread throughout the land which is peat soil has high compressibility and low strength. The construction is going to build on the most famous problematic soil in the geotechnical area. In results of growing construction activities in this area, several experimental testing whether conventional or alternation method has been applied. In addition, peat also considered as unsuitable for supporting foundations and serious problems in construction industry due to its long-term consolidation settlements. According to previous research, Huat [7] have stated that the water content of pet in West Malaysia ranges from 200 to 700% and unit weight of peat is typically lower compared to inorganic soil. The organic content in the range of 50 to 95% and the liquid limit was in the range of 200 to 500%. Furthermore, Duraisamy *et al.,* [8] has reported that tropical fabric causes highest settlement and followed by hemic and sapric when subjected to a load and over the time period while Dhowian and Edil [9] stated that peat soil has low shear strength and high compressive deformation which often results in difficulties when construction undertaken. Thus, examine the peculiar engineering properties and characteristic compressibility of peat soil is importance for engineers to understand and determine suitable ground improvement method [8].

In an area with the ideal topography and climate, organic matter and minerals combine to create the special type of soil known as peat soil [10]. Peat is a mixture of fragmented organic material made of flora that has been chemically changed and fossilised, and it originates in wetlands when the proper climatic and topographical conditions are met [9]. It is a special soil made of minerals and biological material under favourable climatic and topographical circumstances. According to Wang *et al.,* [10] there are 4.153 million square kilometres of peat soil in the world. In comparison to ordinary soft soil foundations, peat soil has a very high-water content, a poor bearing capacity, a high void ratio, a low shear strength, and a high compressibility. Additionally, peat soil has a low PH value and a high degree of sensitivity. Peat soil exhibits anisotropy in terms of its permeability and compressibility, which is frequently unfavourable for engineering building. Building foundation settlement risks result from improper handling [10]. The drainage and compaction of soil will be impacted by poor water permeability. According to research, peats have a high organic matter content and are typically characterised by weak strength, significant deformation, high compressibility, and high magnitude and rates of creep [11]. Klias is situated in the Beaufort district of Sabah, which is part of the northern Borneo Island and has an approximate area of 1,735 km2.

Agriculture is practised on the peat soil that was left after clearing. In order to determine the index properties and features of Sabah peat soil generally, an evaluation of the physical and chemical properties of Klias peat soil has been carried out, along with identification and classification. Klias, which covered a total of 30,900 ha, was degazetted as a forest reserve in 1980 [12], opening the way for development. In general, the engineering industry was unaware of the index properties of the Klias-specific peat soil. Peat soil at Klias Peninsular cannot yet be classified due to a lack of data and knowledge [13].

Peat's physical features include decomposition rate, water content, specific density, bulk density, and other traits. The degree of peat decomposition varies substantially. Peat is often categorised into low, moderate, and high decomposition categories based on the levels of decomposition [14]. The "fist closing" approach was used to divide the degree of decomposition into ten phases. The types of peat-forming plants, various features of peat, and its depositional habitat are all closely tied to how much of it has decomposed. Peat has measured capacities for absorbing and retaining water. Herbaceous-woody peat has the lowest levels of both saturated soil water content and humidity, while sphagnum peat has the highest levels of both [14].

Peat's chemical characteristics include its elemental makeup, organic components, and ash. Peat is made up of the essential components Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), and Sulfur (S). Peat's elemental characteristics often fall between those of coal and wood. Lowly decomposed peat's elemental composition is similar to that of wood, but thoroughly decomposed peat is more like lignite [14]. From analytical researchs, there is a lack of information between bulk density and chemical composition against depth. That being the case, the focal point of this research is to determine the degree of decomposition by determining the chemical composition against depth, bulk density against depth, and decompostion process by using peat sampler on the peat soils at Klias Peat Swamp Forest, Sabah. The intent of this research is to investigate the unordinary engineering behaviour and characteristics of Klias tropical peat in relation to index properties like fibre content, organic content, natural water content, and specific gravity.

Therefore, the study's particular objectives are to study the physical properties of peat soil and determine the decomposition level and in-situ density of peat against depth. Finally, to examine the chemical composition of peat against depth. The purpose of this study's findings is to shed light on and delve further into the use of peat sampler to investigate the unordinary engineering behaviour and characteristics of Klias peat soil in relation to index properties like organic content, pH test, moisture content, fibre content, and specific gravity, which were found and compared to other regions in Malaysia. Additionally, this work adds to earlier studies on peat soil. This study was conducted to close the knowledge gap about the behaviour of peat soil. This method will help engineers understand the issues with peat soil and at the same time introduce a new approach to the line of work.

2. Methodology

2.1 Field and Laboratory Testing

Throughout this research, in order to achieve the objectives, there are some processes and steps are need to be taken. This research is focusing mostly on the type of peat soil which is hemic in Klias-Beaufort. The scope of this study includes the fundamental work and important information regarding the goal of the research that will be conducted. This research was done in Klias, Sabah, a region rich in peat. The investigative programme began with a field study that included analysing peat strata utilizing peat sampler and identifying peat humification in the field against depth.

The degree of decomposition, including other peat traits, was linked to the peat's depositional state and the types of peat forming plants. Organic content, moisture content, fibre content, pH test, bulk density, and specific gravity are some of the index properties of peat soils. By using Field Emission Scanning Electron Microscope (FE-SEM) microstructure of peat was used to carry out the laboratory test. A field emission source releases these electrons, which can be used to identify a peat sample. EDX is used to determine its chemical composition. In order to quantify the local thickness of peat soil layers, a peat sampler is used to collect soil sample at one point and range of depths between 3 to 4 meters at Klias Peat Swamp Field Center (KPSFC). The tests for organic content, pH test, moisture content, fibre content, and specific gravity was done in the Geotechnical Laboratory at University Malaysia Sabah. In wetland ecology, peat coring is a standard operation that can be carried out using a variety of tools, depending on the objectives of the investigation. Early literature has illustrations of some of the first augers. Haglund [15] evaluated early work on peat coring equipment for scientific research in central Europe and Scandinavia. Haglund [15] gave contact details and current prices for the mechanical workshops where these corers were constructed in several instances. The variety of peat coring equipment designs and its relatively wide distribution during the 19th and early 20th centuries may have been a result of the value of peat as a fuel in northern and central Europe at the time.

The cylindrical chamber of the Swedish or "Hiller" sampler [16] is inserted into the peat to a specific depth and is filled by scraping peat off the borehole walls after opening and rotating. [17] created a chamber that collects peat by lateral cutting-off of a half-cylinder peat section out of necessity to preserve the integrity of the peat structure. Couteaux [18] created a two-piece sampler. First, a semi-cylindrical tube is driven into the peat, and then a second one is added in the same spot. A ring fixed at the bottom end of the second semi-cylindrical tube functions as a knife to cut the free surface into a peat core as well as a guide to keep the two tubes together. The core is finally encased in the closed cylinder by rotating the exterior tube. By conserving the peat structure and preventing excessive compaction, this device offers a benefit. Helenelund *et al.,* [19] recommended a large-diameter cylindrical thin-walled sample tube with, preferably, sawblade or wave-shaped edges that must be forced into the ground by jacking and simultaneous zigzag rotation to overcome changes in peat physical properties. Many writers have also employed cylindrical samplers with interior clearances or gradually wider inner diameters to lessen friction between the encased peat core and the sampler's inner wall and to make the extraction of the core easier [20]. The study's particular objectives that were required to be carried out are to study the physical properties of peat soil, to determine the decomposition level and in-situ density of peat against depth and to examine the chemical composition of peat against depth. The flow planning technique used in this research was discussed in more detail in this chapter. In order to establish the study's findings, all necessary components of this analysis were briefly and in-depth described in accordance with BS1377: 1990, British Standard Research Methods for Soil Civil Engineering Purposes, which was applied to the relevant laboratory work and tests in this chapter.

Through lab tests, the index properties that includes moisture content, organic content, fibre content, pH test, bulk density, and specific gravity are determined. Peat Sampler method were used to obtain soil sample and von post scale was utilised to determine the decomposition level. For the Imagenery Analytics, FE-SEM was utilised and for the analysis of chemical properties, EDX was employed. The flowchart of the research is depicted schematically in Figure 1. A comprehensive study into the soil sample process is being conducted, and its procedure is being presented. Samples from various malaysian fields are gathered in one location so that the required sequential soil extraction samples can be carried out.

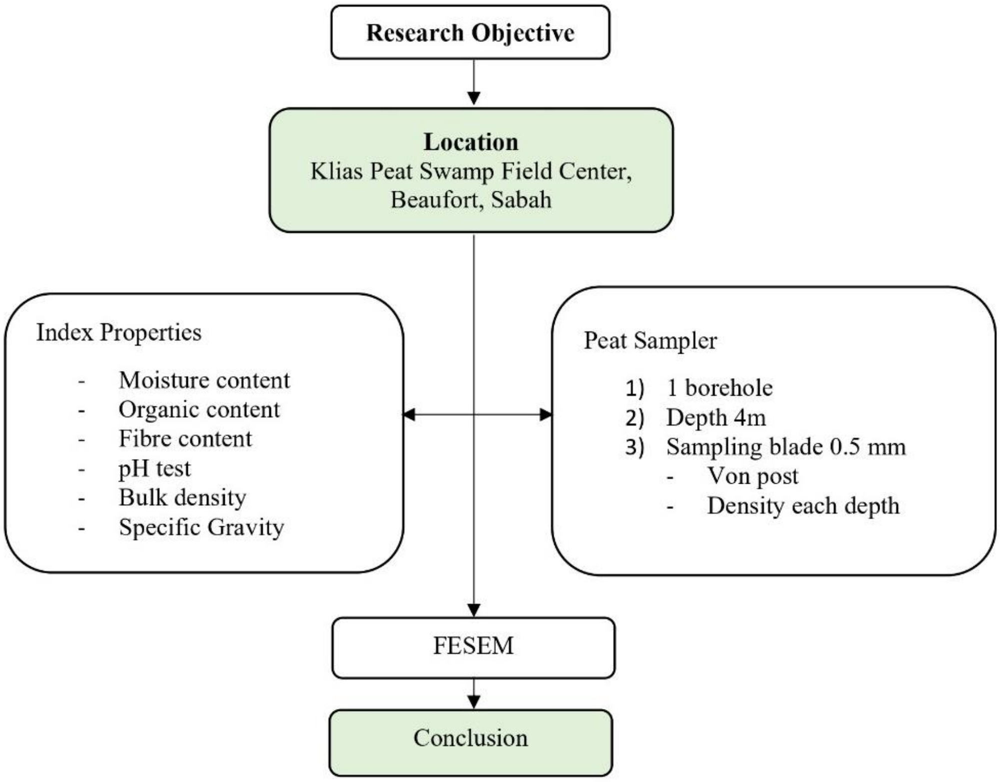

Fig. 1. Research process

The location is noted at Klias Peat Swamp Field Center (KPSFC), in Beaufort Sabah. When there is a sufficient peat soil deposit, the specified location is verified. The Geotechnical Laboratory at University Malaysia Sabah receives the samples after they are taken from site. During the sampling of peat soil on the site, the von post scale is used. Three different types of tests are being conducted in this research, which includes the test for index properties, chemical properties, and imagery analytics. To evaluate the organic content, moisture content, and other index properties, standard tests are conducted, and soil samples are taken. Klias Peat Swamp Field Centre is the site location of this study. It is situated in Beaufort Sabah and this place is well known as a peat deposit area. The Kota Kinabalu-Beaufort highway serves as the main access point. It is situated on the Klias Peninsula about 10 kilometres southwest of Beaufort. From the town of Weston, a boat can be taken to reach the southwest region. The location of the Klias Par Swamp Field Centre is shown in Figure 2.

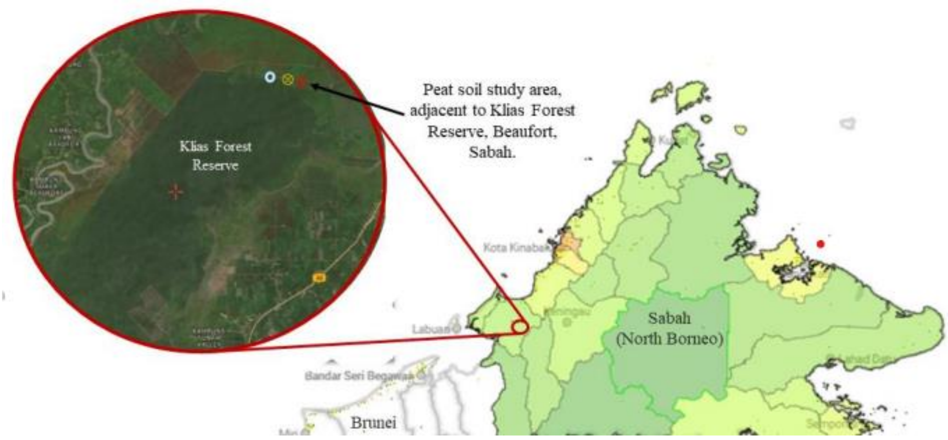

Fig. 2. Klias-Beaufort, Sabah peat location adjacent to Klias Forest Reserve [13]

For the purpose of measuring the local thickness of peat soil layers, a peat sampler is used to take an undisturbed sample at predefined depths for 1 point. To show the peat soil profiles, samples are taken with a length between 3 and 4 metres and penetrated at intervals of 0.5 m up to the soft clay border. Samples are gathered till they reach the clay layers at various depths. From the ground's surface, the peat sampler is manually pushed into the peat soil. The sample blade has a 55 mm diameter and contains a portion of a cylinder. The sampler's 0.15 m height and 0.025 m diameter are filled to a constant volume with peat.

Fig. 3. Peat sampler

Index properties are defined as the soil properties that help to identify the classification and identification of soil. Undisturbed samples are required to examine the in-situ density and relative density, while disturbed soil samples will be used to compute other variables. After the disturbed samples are taken from the site, they are taken to the laboratory located inside University Malaysia Sabah in a plastic bag and placed in a heavy-duty container. Tests are done in the laboratory to distinguish the index properties. Index properties that are determined include moisture content, organic content, specific gravity, fibre content, and pH test. The moisture content is calculated using the terms that follow. A percentage (%) is used to express the moisture content ratio. By drying the soil to a consistent weight and weighing the soil sample both before and after drying at temperatures between 100 and 1100 degrees Celsius in an oven, the quantity of water must be identified. The British Standard BS1377: Part 2: 1990: 3.2, Oven-drying Process serves as the foundation for this test. The majority of soils take 24 hours on average to dry. Dry combustion and elemental analysis are more commonly used in research facilities to determine the overall carbon content of soil, after eliminating any mineral carbonate. The amount of carbon discovered can be interpreted as an approximation of organic matter and vice versa. The hydrogen peroxide method is the approach that is most frequently adopted to evaluate soil organic matter. Calculating soil organic matter involves weighing the soil after it has been subjected to hydrogen peroxide digestion. Peat samples are mixed with hydrogen peroxide in a beaker, which is then foil-wrapped. The sample weights and are used.
The density of soil particles in relation to the density of water is measured by its specific gravity.

It is defined as the ratio of the weight of an equivalent volume of dry water to the dry weight of soil particles. It typically has a value between 2.65 for very light soils and 2.75 for heavy soils, and it is expressed as a dimensionless number. The specific gravity of soil is an important parameter in geotechnical engineering, as it can affect the behavior of soil during construction and other activities. The specific gravity (Gs) of soil is defined as the relationship between the ratio of unit weight of solid particles and the ratio unit weight of water. The specific gravity should not be confused with soil density because it is a dimensionless unit that expresses the ratio of two densities. Specific gravity is a crucial property in soil mechanics due to its relationship to the mineral composition and weathering of the soil. Additionally, it is used to compute several important soil parameters, such as porosity, dry and saturated density, and saturation level. 10 g of 3 samples are prepared. Before weighing, all samples are being held at a low water content, and the 2 cm woody debris is being manually removed. Each choice is made in one of two ways.

A sample is being dried in a porcelain crucible at 105°C for 16 hours to calculate a water-loss factor, representing all results on an oven-dry basis. After oven drying, the samples are being placed in a muffle furnace and heated to 375°C for 16 hours to measure the ash content. In the presence of carbonates, the amount is being estimated and the ash content is being adjusted. Hydrogen ions that can be found in the soil are being analyzed by a soil pH (potential hydrogen) test. A pH test is conducted to determine if the soil is alkaline (pH greater than 7), acidic (pH less than 7), or neutral (pH equal to 7). The pH test is performed in accordance with BS1377: Part 3: 1990.0 standards. An electrometric method is used to measure the pH of the peat soil.

To ensure the success of the procedure, three samples are being tested, and sample preparation is done using a 2 mm sieve. It is essential to collect multiple measurements at the same area throughout time and at various depths in the soil to account for variability, for instance at 10, 30, and 50 cm depths to look at both the surface soil and subsoil. For this research, sample of peat soils are collected from the desired depth, which are 0.5 m to 4.0 m.

FE-SEM stands for Field Emission Scanning Electron Microscope. It is a type of microscope that uses a beam of electrons to scan a sample and produce high-resolution images of its surface. In soil investigation, FE-SEM is used to analyze the physical and chemical properties of soil samples. It examines the surface structure, composition, and morphology of soil particles, as well as the distribution of minerals and other components within the soil. FE-SEM proves particularly useful in soil investigation due to its ability to analyze samples at a very high magnification, typically up to 50,000x. This allows for the detection of very small features and structures within the soil sample that might not be visible with other techniques. Moreover, it identifies the presence of specific minerals or organic compounds in the soil and studies the texture, porosity, and other properties of soil particles as discussed [39].

The process begins with carefully preparing and cleaning the sample to remove any contaminants that might interfere with the electron beam or imaging process. The sample may also be coated with a conductive layer, such as gold or palladium, to prevent charging and enhance the electron-sample interaction. Subsequently, the sample is loaded into the FE-SEM, usually by mounting it onto a stub with a conductive tape, and then transferred into the vacuum chamber of the FE-SEM. The vacuum chamber is pushed down to a high vacuum to limit the interference of gas molecules with the electron beam. An electron beam is produced from the field emission source and focused via electron lenses onto the sample surface. By scanning the electron beam over the sample's surface, images of the sample's surface and internal structure are created, producing a variety of signals. Computer software is utilized to automate and regulate the image process. Finally, the images generated by the FE-SEM are analyzed to extract information about the physical and chemical properties of the sample.

Energy-dispersive X-ray spectroscopy (EDX) is a technique used to determine the elemental composition of materials. It works by bombarding the sample with a beam of electrons, which knocks electrons out of the atoms in the sample. When these electrons are replaced, they emit X-rays with characteristic energies that can be used to identify the elements present in the sample. EDX is used to determine the chemical properties of peat soil. It can be used to identify the different elements present in peat soil, including carbon, nitrogen, phosphorus, sulfur, potassium, calcium, magnesium, and iron. This information can be used to understand the chemical properties of peat soil and how it can be used for different purposes.

3. Results and Discussion

3.1 Sample with Various Depth

The implications of this study were covered in this part after the preliminary research outcomes. Based on index properties from past studies by various researchers, Table 1 presented tabular data on Malaysian peat soil characteristics. As a result, the main goal of this study was to incorporate previous research findings. In order to examine KPSFC's characteristics and ensure that the specified ranges of results were achieved, the findings of this study were compared with previous data. The moisture content obtained for each sample by using the moisture content equation are 263.313 percent, 250.784 percent, and 259.857 percent for sample 1, sample 2, and sample 3 respectively. The average moisture content is 257.985 percent. The range of Malaysian peat soil's water-holding capacity is 96 to 2200 percent [21]. Which is substantially higher than the moisture content of clay and silt deposits, which rarely goes above 200 percent. Due to the peat structure's large pore space and the distance between the particles, which allows for rapid water movement, the soil may hold plenty of water [22]. To compare the result of moisture content obtained at KPSFC from previous researches, Sapar *et al.,* [23] obtained 673.99 percent of moisture content, Mohamad and Zainorabidin [24] obtained an average of 713.35 percent of moisture content, and Talib *et al.,* [13] obtained 687.03 percent of moisture content.

The difference in moisture content obtained between this research and previous researches may due to several factors such as time, season, and changes in the water table level. Due to factors including the origin of the fibre, temperature, environment, and humidity, the content of peat varies from place to place [7]. During the collection of samples, it was during the dry season which certainly diminished the amount of moisture content in the site.

A total of 3 samples were taken for the organic content test. The organic equation was used to calculate the organic content of each peat soil sample. The organic content obtained are 93 percent, 89 percent, and 93 percent for sample 1, sample 2, and sample 3 respectively. The average loss of ignition from the organic content test obtained was 91%. Malaysian peat soils have an organic content that ranges from 70 percent to 98 percent [25]. Sapar *et al.,* [23] obtained 99.42 percent of organic content, Mohamad and Zainorabidin [24] obtained an average of 65.22 percent of organic content, and Talib *et al.,* [13] obtained 98.94 percent of organic content. The organic content percentage for this research falls in the range of the previous researches. According to Talib *et al.,* [13], these outcomes are impacted by the soil's initial composition, which included decomposed leaves, roots, and other elements. Peat's organic content in the research area rises as soil moisture levels do [23].

For the fibre content test, 3 samples were taken to determine the average value of fibre content. The percentage of fibre obtained were 74.79 percent, 78.36 percent, and 71.93 percent for sample 1, sample 2, and sample 3 respectively. The average fibre content obtained was 75. 03 percent. Sapar *et al.,* [23] obtained 67.03 percent of fiber content, Mohamad and Zainorabidin [24] obtained an average of 70.97 percent of organic content, and Talib *et al.,* [13] obtained 66.41 percent of organic content. The percentage of fibre content obtained for this research are almost similar to the previous researches, just slightly higher.

Environmental factors such as temperature might causes the slight differences in the result obtained as it can influence the growth and productivity of vegetation in peat soil. Peat is formed through the accumulation and burial of organic particles, primarily derived from decaying plant material. Therefore, the growth and composition of peat fibers are primarily influenced by the decomposition of plant matter [13]. The percentage of fibre content will affect the degree of decomposition. The higher the fibre content, the lower the degree of peat decomposition and vice versa [26]. The pH value drops to 3.6 from 3.8 for sample 5 and 6 may be caused by error during lab work. Besides, it could also be due to presence of decomposing plant material. For the pH test, a total of 8 samples were taken to determine the pH value for each depth of peat samples. The average pH value obtained from the test was 3.7 which is considered as acidic.

Sulaiman *et al.,* [27] obtained a pH value of 3.1 for the peat sample acquired from the KPSFC, Sutejo *et al.,* [28] obtained a pH value of 3.16 from the peat sample extracted from the village III Banyu Urip, Regency of Banyuasin, South Sumatera province, and Zolkefle *et al.,* [29] obtained a pH value of 3.72 for the peat sample acquired at Pontian, Johor. The pH value obtained for this research are similar to previous researches which in the range of 3.0 to 3.8. A total of 3 samples were taken for the specific gravity test of peat soil. The specific gravity obtained are 0.646, 0.766, and 77.7 for sample 1, sample 2, and sample 3 respectively. The peat sample taken in this investigation has an average specific gravity of 0.748. Kolay *et al.,* [30] stated that tropical peat usually has a specific gravity of 1.0 to 1.7. To compare with past researches, the specific gravity obtained by Mohamad and Zainorabidin [24] is 1.28, and Sapar *et al.,* [23] obtained a specific gracity of 1.22. The specific gravity obtained from this research is lower compared to the stereotypical specific gravity value of peat soil. Figure 4 shows the Von post scale on field.

Table 1
Index properties results

No.	Ref.	Atterberg Limit (%)		Natural Moisture Content (w, %)	Specific Gravity (G_s)	Acidity (pH)	Organic Content (%)	Fiber Content (%)
		I_p	w_L					
1.	Author	-	-	257.985	0.748	3.6	91	75.03
2.	[31]	-	-	668	1.40	3.51	96	90
3.	[28]	-	-	236.523	1.869	3.2	77.690	-
4.	[32]	134	305	247	1.572	-	63	-
5.	[33]	-	208.39	555	1.24	3.50	96.45	90.39
6.	[7]	-	-	-	1.38		65-97	-
7.	[34]	-	55	40	2.3	-	35	
8.	[35]	-	202.3-220.7	198-417	0.95-1.34	3-5	41-99	31-77
9.	[36]	202-243	388-412	507-544	1.67-1.81	4.43-4.96	25.7-31.9	32.6-37.1
10.	[37]	-	-	678	1.63	-	-	32.5

Most researches evaluate the level of on-site humification using the Von Post classification [38]. In the von Post humification test (also known as the von Post classification system), the peat and material that is secreted are squeezed between the fingers, examined, and the soil is then classified as belonging to one of ten groups of humification or decomposition (H1-H10). The von post method was done at site (KPSFC), and the peat soil can be classified as H5-H6, which indicates muddy to strongly muddy for the peat. The von post scale method is shown in Figure 4.

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Fig. 4. The method of Von Post Scale to determine the degree of decomposition

The visual interpretation of soil layers is shown in Figure 5. Each soil layers are 0.5 meters long, and the total depth of soil extruded is 4 meters. Therefore, a total of 8 samples were collected. The weight for each soil sample were taken and were tabulated in Table 2.

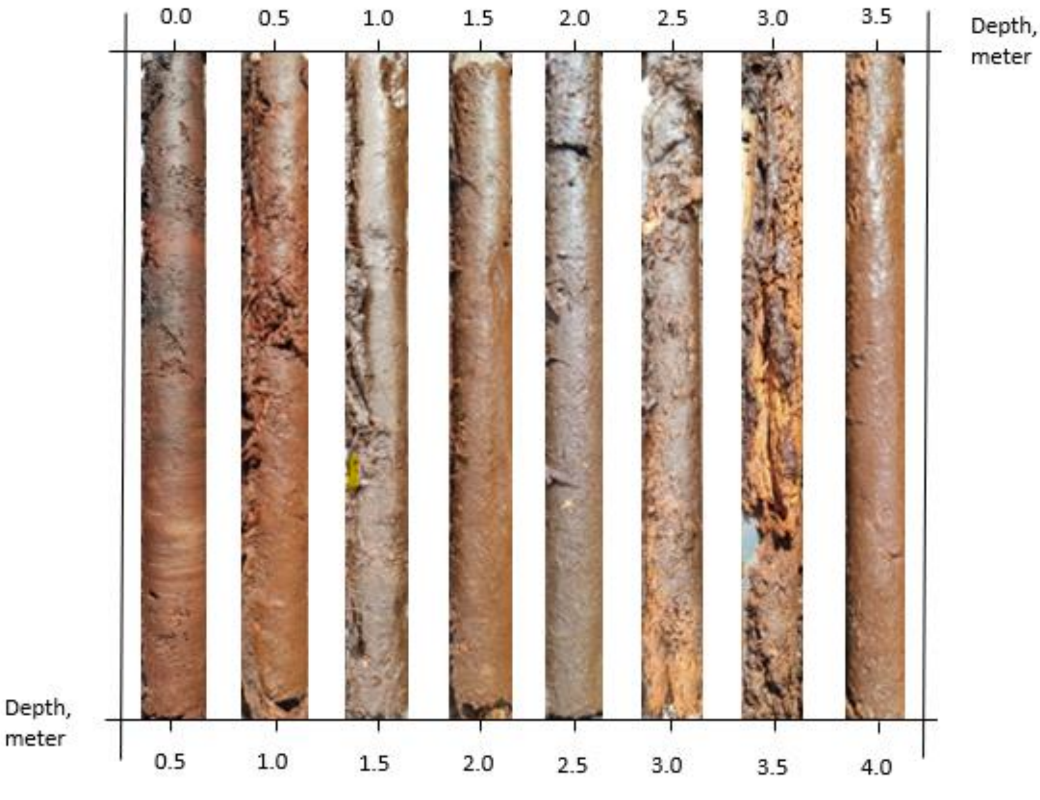


Fig. 5. The soil profile of the peat sample for depth between 0 to 4 meters

Table 2
Weight of sample for each depth

Depth (m)	Weight (kg)
0.5	0.62
1.0	0.64
1.5	0.70
2.0	0.68
2.5	0.76
3.0	0.82
3.5	0.70
4.0	0.68

By observing the soil profile, there are some differences that can be seen for each layer of peat soil. From depth 0 to 0.5 meters which is considered as shallow peat, it can be observed that the peat profile is slightly loosen on top and became denser on the lower part. From depth 0.5 to 1.5 meters, the peat consists of decomposed materials like plants and roots, and voids can be seen and it is fibrous and succulent. The soil profile started to become denser from the depth of 1.5 to 2.5 meters but still in wet condition. Higher stress is thought to have resulted from the layers being pressed together more tightly than the top layers due to increased depth and water pressure. Notably, peat becomes denser as it goes down deeper [13]. From depth 2.5 to 3.5 meters, decomposed materials such as woods and plant roots are present. Finally on depth 3.5 to 4 meters, the peat profile became denser but also in wet condition. The color of the peat from 0 to 4 meters are similar which means that the clay soil layer is located deeper. From the result and analysis of the samples observed, there are no outstanding differences between the soil profiles. The color for each layer is similar to each other which is dark brown. Decomposed materials are present at both shallow layer and deeper layer and the condition of peat soil is wet.

The wet condition may be caused by high water table, which means that the peat soil constantly in contact with the water. The bulk density was calculated for each depth layer and is shown in Figure 6. The density of peat soil is significant for several reasons such as soil classification, water holding capacity, and strength and stability. By observing the pattern in Figure 4.7, the density becomes higher as the depth becomes deeper. But the density drops after the depth reaches 3.5 meters. The density is higher on depth 2.5 to 3 meters. This outcome may be caused by the number of decomposed materials such as roots and woods which resulted a higher density value. Table 3 shows the FESEM results against depth (m) of peat soil. The results near found and stated [40,42] that the scanning Electron Microscopy (FESEM) images for peat soil shows the untreated peat the origin peat observed highly voids, pores, and spaces in between the peat structure. FESEM test observed a variety of features and components within the peat soil, providing valuable insights into its composition and structure as shown in Table 3.

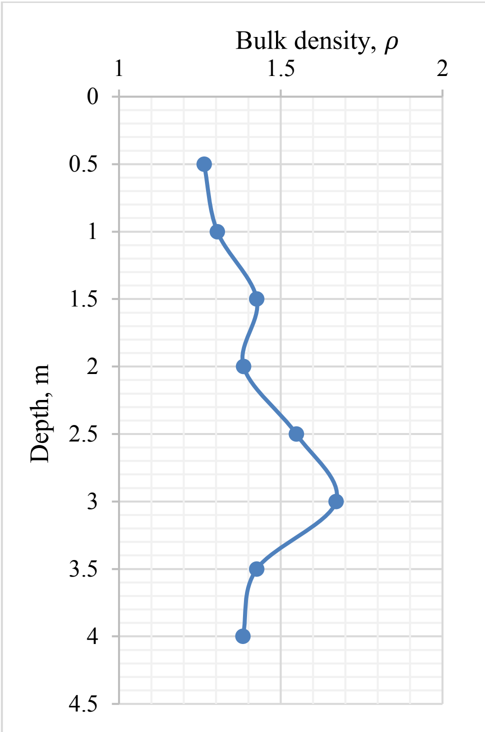
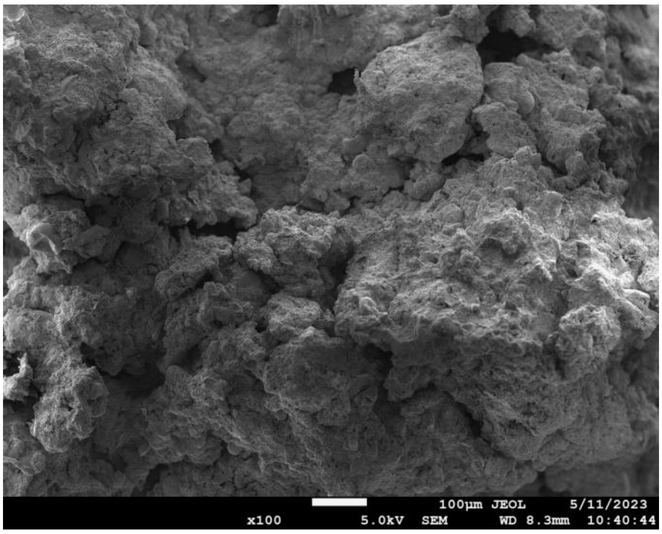
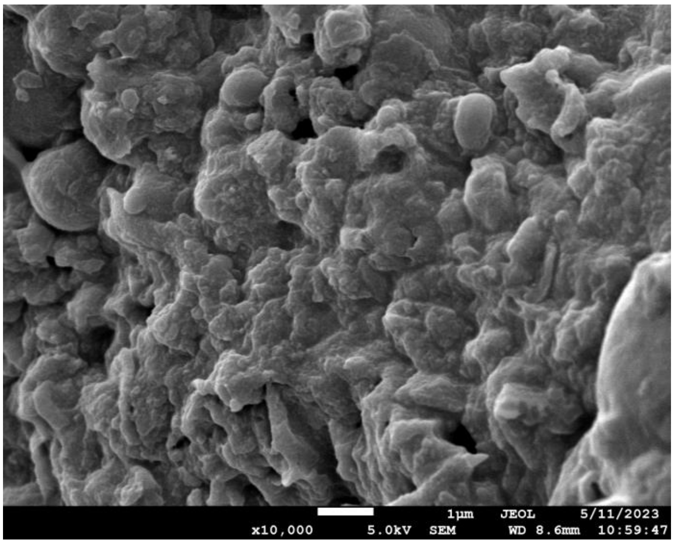
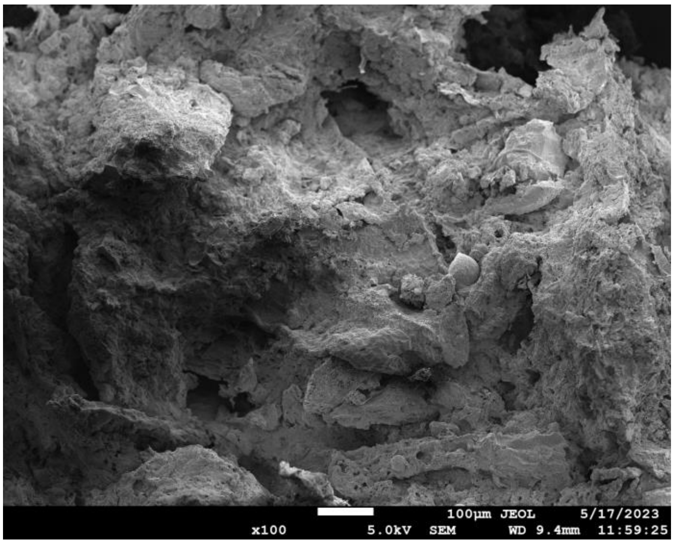
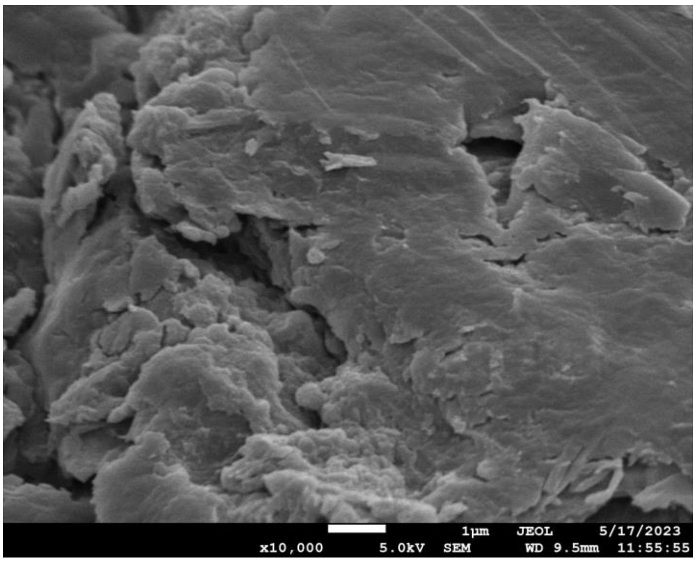


Fig. 6. Bulk Density against depth (m)

Table 3
Weight of sample for each depth

Depth (m)	FESEM	Description
0 – 0.5	 Peat soil sample enlarged for 100 times at 0 to 0.5m depth	Pore spaces and voids can be seen on the peat soil sample that was enlarged for 100 times. The pore sizes are generally the same size. The sample exhibits rough surface texture and irregular pore formation.

Depth (m)	FESEM	Description
0 – 0.5	 Peat soil sample enlarged for 10,000 times at 0 to 0.5m depth	The peat sample that was enlarged for 10,000 times can be seen colloid with voids. The pore sizes are mostly identical. The sample displays rough surface with irregular pore formation. Fibre content can also be observed.
3.5 – 4.0	 Peat soil sample enlarged for 100 times at 3.5 to 4.0m depth	For the peat sample that was enlarged for 100 times, the sample can be seen porous with big voids. The sample exhibits various pore sizes, with predominantly big interconnected voids. The surface can be seen rough and flaky.
	 Peat soil sample enlarged for 10,000 times at 3.5 to 4.0m depth	Pore spaces and voids can be seen on the peat sample that is enlarged for 10,000 times. The sizes of the voids are generally the same. The surface appears to be smooth, with some part shows small clusters of particles. A fragment of organic content can also be seen on the peat sample.

The silicon (Si content developed from each spectrum ranged from 14.4% to 17.7%. The EDX results show significant results where mineral crystallization occurred in the coagulation process [40]. The minerology of peat soil is shown in Table 3, where the Energy dispersive X-ray analysis (EDX) spectrum of peat The EDX results show significant results where mineral crystallization occurred in the coagulation process [42]. Thus, In various aspects, peat soil is different from mineral soil. Peat is a biogenic deposit that emerged within the last 10,000 years, during the post-glacial (Holocene) era [41]. For particulate material, the micro-structurally of peat consists of organic material that is formed in fiber, woody material, roots, dead plants, and decomposable matter [43]. EDX provides information about the elemental composition of a sample. When applied to peat soil, EDX results revealed the presence and relative abundance of various elements within the soil.

EDX test detected a wide range of elements, from hydrogen (H) to uranium (U). Common elements found in peat soil may include carbon (C), oxygen (O), hydrogen (H), nitrogen (N), sulfur (S), as well as minerals like silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), and others as shown in Table 3. For 0-0.5 m depth, the carbon content is 71.5% and 3.5-4.0 m, the carbon increased significantly to 75.6% as the deeper the peat, the higher the carbon content due to the decompositions process and accumulation of peat.

A total of 8 samples were taken to the PIPS laboratory. The chemical composition for each depth were obtained. From the result shown in Table 4.8, from depth of 0 to 0.5 meters, the chemical composition of carbon, oxygen, and sulphur are 71.5 percent, 28 percent, and 0.1 percent respectively. From depth of 0.5 to 1.0 meters, the chemical composition of carbon, oxygen, and sulphur are 60.1 percent, 36.2 percent, and 3.4 percent respectively. From depth of 1.0 to 1.5 meters, the chemical composition of carbon, oxygen, and sulphur are 72.1 percent, 26.6 percent, and 0.4 percent respectively. From depth of 1.5 to 2.0 meters, the chemical composition of carbon, oxygen, and sulphur are 73.7 percent, 24.6 percent, and 0.9 percent respectively. From depth of 2 to 2.5 meters, the chemical composition of carbon, oxygen, and sulphur are 74.0 percent, 25.1 percent, and 0.3 percent respectively. From depth of 2.5 to 3.0 meters, the chemical composition of carbon, oxygen, and sulphur are 75.5 percent, 23.8 percent, and 0.3 percent respectively. From depth of 3.0 to 3.5 meters, the chemical composition of carbon, oxygen, and sulphur are 80.4 percent, 17.8 percent, and 0.6 percent respectively. Finally, from depth of 3.5 to 4.0 meters, the chemical composition of carbon, oxygen, and sulphur are 75.6 percent, 23.8 percent, and 0.2 percent respectively. Carbon is the most abundant chemical in the sample followed by oxygen and sulphur. By observing Figure 7, the value of sulphur for each depth are relatively small except for depth 0.5 to 1.0 meters which is 3.4 percent. The percentage of oxygen decreases as the depth increases. Notably, the oxygen is higher for depth 0.5 to 1.0 meters. The percentage of carbon increases as the depth increases but it can be observed that it decreases on depth 0.5 to 1.0 meters. By analysing this pattern, the chemical composition of peat soil on the 0.5 to 1.0 meters is slightly unusual. This may be caused by the presence of decomposed materials that may result in inconsistent chemical composition value.

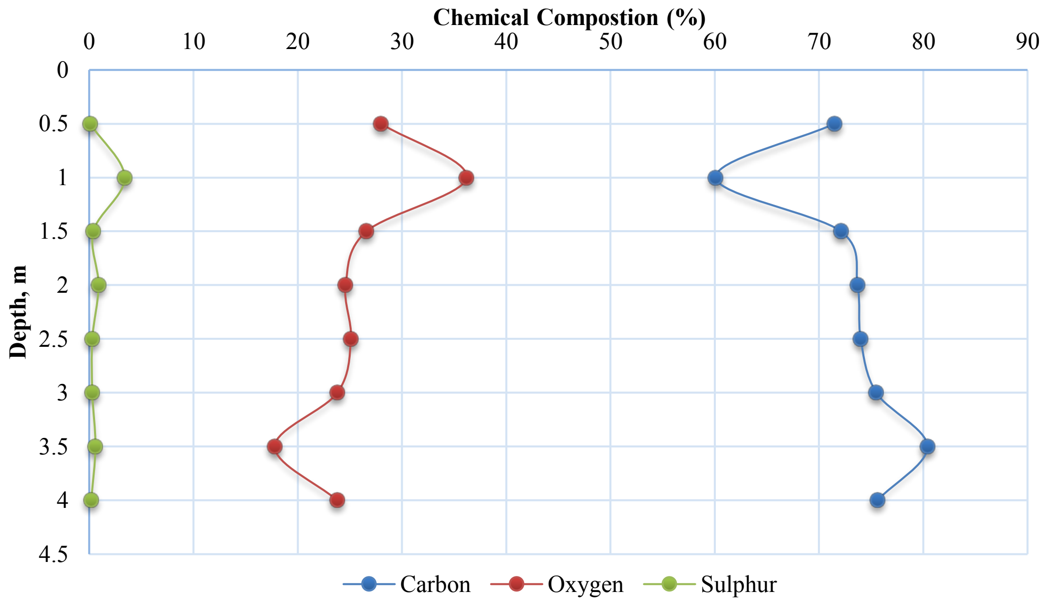
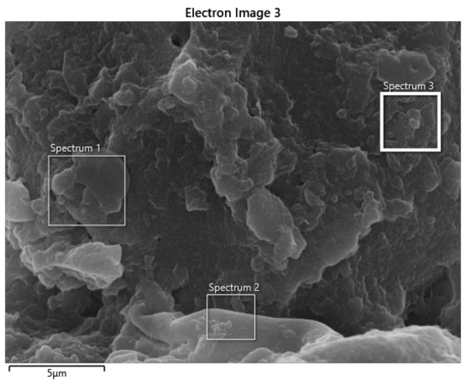
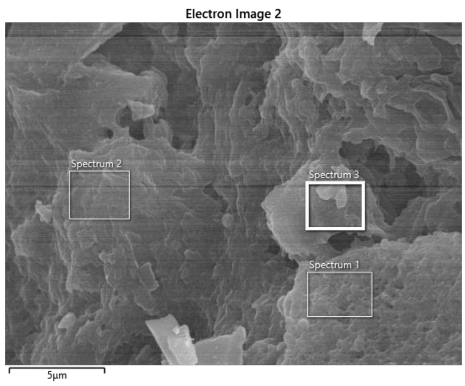
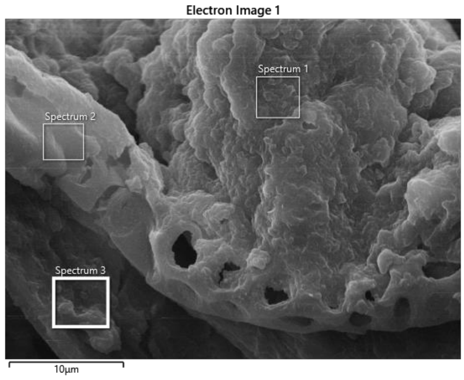
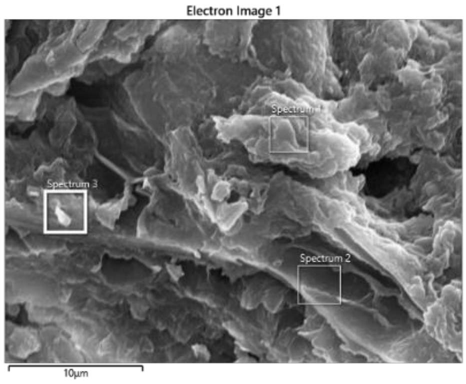
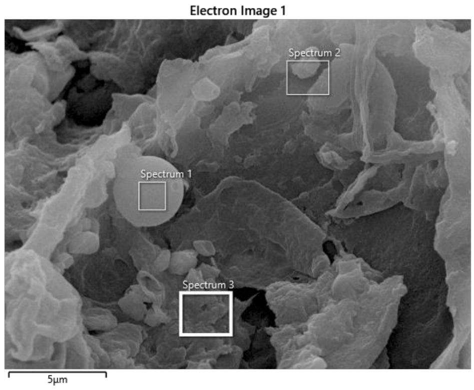
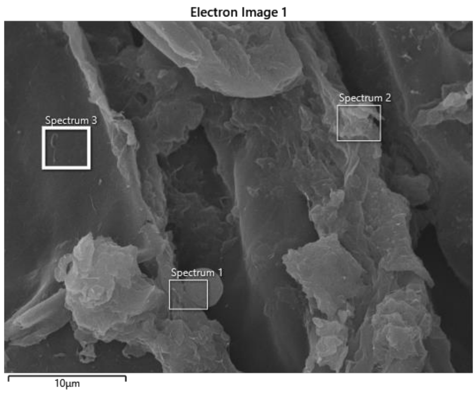
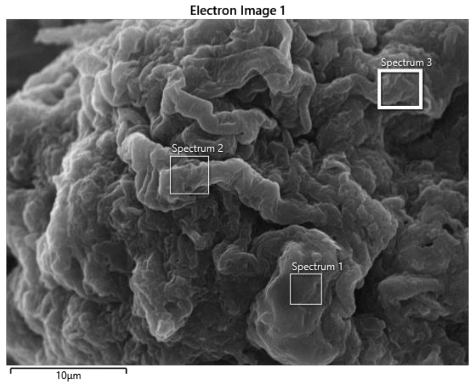
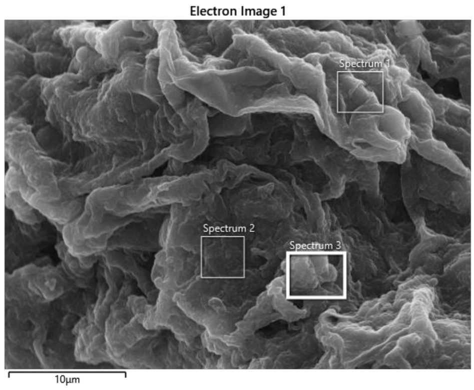


Fig. 7. Depth against Chemical Composition for Carbon, Oxygen, and Sulphur Graph

Table 4
The EDX result for the soil samples

Depth	Composition (%)			Spectrum
	Carbon	Oxygen	Sulphur	
0 – 0.5	71.5	28.0	0.1	
0.5 – 1.0	60.1	36.2	3.4	

1.0 – 1.5	72.1	26.6	0.4	
1.5 – 2.0	73.7	24.6	0.9	
2.0 – 2.5	74.0	25.1	0.3	
2.5 – 3.0	75.5	23.8	0.3	

3.0 – 3.5	80.4	17.8	0.6	
3.5 – 4.0	75.6	23.8	0.2	

4. Conclusions

The average moisture content of the peat soil samples obtained in this research is 257.985 percent. The difference in moisture content compared to previous researches can be attributed to various factors such as time, season, and fluctuations in the water table level. Next, the average loss of ignition from the organic content test indicates that the peat soil samples have an organic content of 91%. This falls within the range of previous researches, demonstrating consistency in the organic composition of the peat soil in the study area. The organic content is influenced by the initial composition of the soil, which consists of decomposed leaves, roots, and other organic elements. The average fibre content of the peat soil samples was determined to be 75.03 percent. The slight differences observed in the results may be attributed to environmental factors, particularly temperature, which can impact the growth and productivity of vegetation in peat soil. Besides, the average pH value of the peat soil samples obtained in this research was 3.7, indicating an acidic nature. These results align with previous research findings, which also reported pH values ranging from 3.0 to 3.8 for peat soils. Nevertheless, the average specific gravity of the peat soil samples in this research was 0.748, which is lower than the typical specific gravity value of peat soil. The discrepancy in results can be attributed to the use of a reduced soil sample weight (15g) compared to the recommended weight (30g).

Overall, environmental factors and variations in sample collection can impact the results of peat soil analysis, highlighting the need for careful consideration and standardization in future research. Considering the results obtained from this study, it can be inferred that peat soil is a problematic soil. In conclusion, the soil profile analysis reveals distinct variations in peat density and composition at different depths. Peat becomes denser as depth increases, with notable layers of decomposed materials such as plants and roots present at specific depths. The consistent dark brown color suggests uniformity in the peat's organic content throughout the layers. The wet condition of the peat soil is likely influenced by the high-water table, maintaining constant contact with water.

Understanding these soil profiles and densities is crucial for soil classification, water holding capacity, and overall strength and stability assessments.

The microscopic examination of the peat soil samples revealed the presence of pore spaces and voids at both 100x and 10,000x magnifications. The samples displayed rough surfaces with irregular pore formations, and the pore sizes were generally similar. Additionally, fiber content and fragments of organic material were observed in the samples. The chemical composition of peat soil was analyzed at different depths, revealing varying percentages of carbon, oxygen, and sulphur. Carbon is the most abundant chemical across all depths, followed by oxygen and sulphur. The presence of decomposed materials at specific depths, especially at 0.5 to 1.0 meters, may contribute to the slightly unusual chemical composition observed in the peat soil. Careful consideration of these variations is essential when assessing the overall characteristics and behavior of the peat soil.

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