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Research Paper

Identifying the Original Source of Megalithic Stones in Tambunan Using Spectral Signature Technique

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Abstract
Megalithic stones are a remnant of the ancient people. An intriguing megalithic stone legacy ought to emphasize the context in which it fits. Consequently, it is necessary to ascertain each megalithic stone's historical context. This is significant for the archaeologist to obtain true and valid information. In Tambunan, there are numerous myths about megalithic stones. As a result, it is impossible to verify the story's validity. These days, remote sensing has emerged as a crucial technical instrument for archaeologists to gather spatial data in both broad and localized locations. Prior research has demonstrated the efficacy of remote sensing in identifying archaeological site remnants. Nevertheless, there have never been any investigations utilizing remote sensing in relation to small-sized megalithic stones. Thus, this study employs spectral signature techniques and remote sensing to identify the original source of the megalithic stones discovered in Tambunan. This study carries out the spectral signature of megalithic stones in Tambunan using Sentinel-2A satellite image data with a 5-meter resolution using the SNAP application. Before that, the coordinates and measurements for each megalithic stone were obtained from the ground. The spectral signature of all the megalithic stones was then compared with the spectral signature of the stones near the river or near the hill. The study's findings demonstrate that the spectral signature of the megalithic stones in question is identical to the stone found in the river near its location. As a result, this study was successful in providing scientific evidence that the river is the source of the megalithic stones in Tambunan, despite the stones' considerable distance from their site.

Keywords
Megalithic Stone, Myths, Remote Sensing, Spectral Signature, Tambunan

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1. INTRODUCTION

As a cultural practice that involves the production and regulation of a spectrum of values and ways of understanding, a cultural heritage is defined as the imprint of memory and forgetfulness. The collection of artifacts left behind by human activity, both deliberate and accidental, tangible and ethereal, make up this footprint, which also serves as a representation of social and historical processes (Harrison et al., 2020).

One of the cultural heritages of the Kadazan Dusun community in Sabah is the megalithic tradition (Sieng and Eboy, 2021). The megalithic tradition is related to the background and interesting stories around it. This is also related to the practices or lives of nearby villagers. In the past, villagers used megalithic stones for purposes such as worshiping the spirits of ancestors, commemorating someone who has died, or marking areas or boundaries (Sieng et al., 2023).

There are several myths related to megalithic stones in Tambunan. One of them is a stone made from a bobolian. According to myth, a bobolian was turned to stone because his son was slow to bring him fire when he was performing a ritual to cure a terminally ill patient. When his children hugged him, they too turned to stone (Phelan, 1997). In addition, there are stones that are made of pregnant women laughing at animals (Sieng et al., 2023). The stone is known as a pregnancy stone. In addition, according to the legend, there is a round stone that originally came from a wild boar hunted by a group of hunters from Kampung Kedundung. When the hunter threw a spear at the wild boar, the boar was not visible; instead, the spear stuck on a large stone covered in blood (Sieng and Eboy, 2021).

However, those stories are just legends and myths handed down from our ancestors. Therefore, the authenticity of the story cannot be confirmed. Therefore, the authenticity of the story cannot be confirmed. Furthermore, the megalithic tradition is long gone. This raises the question of the origin of the megalithic stone that still exists at present. In this era of rapid information technology revolution, remote sensing has become an important tool in many fields (Eboy and Kemarau, 2023), including the field of archeology (Chen et al., 2017; Tapete, 2018; Agapiou and Lysandrou, 2023). Archaeological studies, especially megalithic ones, using remote sensing have become increasingly popular nowadays. Adamopoulos and Rinaudo (2020) have used remote sensing to detect exposed and underground archaeological remains. Dimitrios et al. (2016) have used a diverse approach based on satellite images to trace neolithic settlements in Thessaly to illustrate the advantages of satellite remote sensing in archaeological studies. In Malaysia, remote sensing and GIS were used in the documentation study of the archeology site of Bujang Valley, Kedah (Roslan et al., 2021; Aminuddin et al., 2019).

Therefore, the effectiveness of remote sensing in detecting the remains of archaeological sites has been proven in previous studies. However, studies related to small-sized megalithic stones using remote sensing have not been carried out before. Therefore, this study uses remote sensing to detect the original source of small-sized megalithic stones found in Tambunan through spectral signature techniques. Stones that have the same spectral curve are the same object (Duong et al., 2014). This shows that the original source for megalithic stones has the same spectral signature. Spectral signature techniques have indeed been used in previous studies to identify the source of an object, but this technique has not yet been used in the study of megalithic stones, especially small-sized megalithic stones (Duong et al., 2014; Padma and Sanjeevi, 2014; Chen et al., 2016). The novelty of this study lies in its pioneering application of spectral signature techniques through remote sensing to identify the original source of small, megalithic stones in Tambunan. Remote sensing has been extensively used in archaeology to detect larger archaeological remains and features, but this research is the first to specifically focus on small-sized megalithic stones. This study fills a critical gap by providing a scientific method to trace the origins of these stones, which were previously surrounded by myths and unverified stories. Utilizing Sentinel-2A satellite imagery with a 10-meter resolution, the research compares the spectral signatures of the megalithic stones with those of stones from nearby rivers, establishing a robust scientific basis for their origins.

This study differs significantly from previous work in several key aspects. First, it focuses on small-sized megalithic stones, unlike earlier studies that primarily targeted larger archaeological sites and artifacts. This shift addresses a previously overlooked area in archaeological remote sensing studies. Second, the application of spectral signature techniques to small, megalithic stones is unprecedented. While these techniques have been used for identifying various objects in remote sensing, their application to such specific and localized archaeological elements is a novel contribution. Third, the study leverages Sentinel-2A satellite imagery, which offers a resolution particularly advantageous for identifying smaller features, contrasting with prior studies that may have used different satellite data or focused on other resolutions and scales. Lastly, the study ensures accurate comparison of spectral signatures by obtaining coordinates and measurements directly from the field, a rigorous ground validation step that distinguishes it from earlier works that relied more heavily on remote sensing data alone.

In summary, this research breaks new ground by applying spectral signature techniques to small-sized megalithic stones, providing a scientific method to verify their origins and countering myths with empirical evidence. The innovative use of Sentinel-2A data and the rigorous methodological approach further underscore the study's contribution to the field of archaeological remote sensing.

Archaeologists have realized the potential of remote sensing in archaeology. Remote sensing can detect surface phenomena related to subsurface artifacts through aerial photography (Palermo, 2022; Adamopoulos and Rinaudo, 2020; Rogerio-Candelera et al., 2018). Remote sensing helps archaeologists reach study areas, better plan site-based studies, and understand monuments on a larger scale than their setting (Agapiou et al., 2023; Liu et al., 2023; Cutillas-Victoria et al., 2024).

The spectral signature is a fundamental concept in spectral remote sensing. The spectral signature determines the unique relationship between a material and its reflectance (Huang et al., 2022). All objects have different spectral signatures due to different spectral properties in reflection and absorption. Therefore, spectral signatures can be used to distinguish land cover (Batista et al., 2022; Wang et al., 2022) and can provide important information about the land cover. The two-dimensional plot of the spectral signature is the spectral reflectance curve (SRC), the shape of which is formed by the varying amplitude of the reflection. Therefore, similar curve shapes are inferred to be the same material. In general, to detect an object in the field, the spectral reflectance curve needs to be compared with the spectral one in the library (Duong et al., 2014).

Sentinel-2 data is an image observed from the surface of the earth and the same area by two satellites (A and B) that have a fixed time period of five days. Sentinel-2 data is free and available to Copernicus Open Access users. The resolution of the sensor used to observe Sentinel-2 data is very high and reaches a maximum of 10 meters. The sensor used is multispectral and obtained from 12 separate bands. Some previous researchers have conducted studies using Sentinel-2 image data such as Agapiou et al. (2014) who evaluated their potential for the detection of archaeological plant marks in Paphos (Cyprus), Zanni and De Rosa (2019) who identified and reconstructed ancient viability between the Roman cities of Aquileia (Aquileia, Italy) and Singidunum (Belgrade, Serbia), through a vegetation index derived from Sentinel-2 data; Khalaf and Insoll (2019) who explored open source satellite images, including Sentinel-2 for monitoring and protection of Islamic archaeological landscapes in Ethiopia; Agapiou et al. (2014) evaluated the potential synergistic use of multitemporal Sentinel-1 and Sentinel-2 data sets to image and extract archaeological features of neolithic landscapes semi-automatically in the Thessalian plain; Kalayci et al. (2019) performed a quantitative assessment of the spectral response of hollow roads in Mesopotamia using a set of remote sensing dates including Sentinel-2 images; Abate et al. (2020) evaluated the potential of Sentinel-2 data for preventive archeology at two test areas in Southern Italy comparing various approaches for data enhancement, and semi-automatic and automatic feature extraction and another by Agapiou (2020) that evaluate Landsat 8 and Sentinel-2 for image segmentation of archaeological landscapes and proxies.

Therefore, by using Sentinel-2 image data, the studies have been successfully conducted. According to Agapiou et al. (2014), the spectral characteristics of Sentinel-2 are very good for distinguishing crop marks compared to existing satellite sensors. In addition, by using Sentinel-2 images, it is not only possible to detect buried archaeological sites but also to detect archaeological sites that have never been explored. Therefore, Sentinel-2 data is suitable for conducting spectral signature analysis to detect archaeological sites.

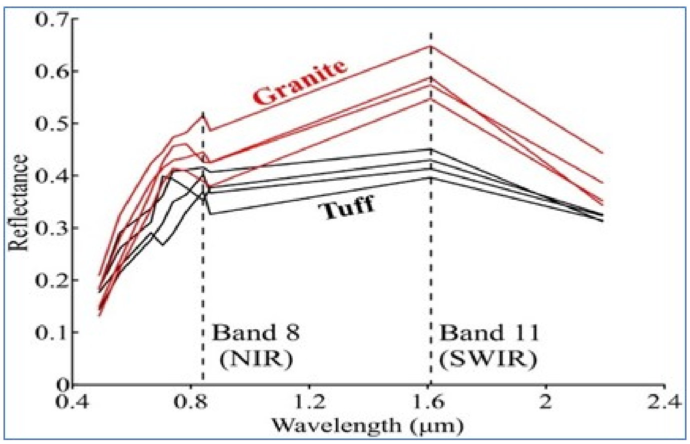

Figure 1. Spectral Signature of Granite Stone (Courtesy of Lin et al. (2019))

The spectral signature determines the unique relationship between a material and its reflectance (Huang et al., 2022; Khan et al., 2018). All objects have different spectral signatures due to different spectral properties in reflection and absorption. The two-dimensional plot of the spectral signature is the spectral reflectance curve (SRC), the shape of which is formed by the varying amplitude of the reflection. Therefore, similar curve shapes are inferred to be the same material. In general, to detect an object in the field, the spectral reflectance curve needs to be compared with the spectral one in the library (Duong et al., 2014).

Megalithic stones usually represent mineral materials (Rahman, 2016). Figure 1 shows the spectral signature curve of a granite stone, which is a mineral material carried out by Lin et al. (2019). Based on this reference, this study was able to identify the types of stone for the megalith by comparing the spectral signature curve of the megalithic stone with the spectral signature curve of the stone near the river. Thus, if both spectral signatures are the same, it proves that the megalithic stone originated from the river even though the stones are quite heavy.

Based on the above, spectral signatures have been used before this in previous studies to identify the source of certain objects. However, it has not been used for small objects such as the small-sized megalithic stones (Duong et al., 2014; Padma and Sanjeevi, 2014; Chen et al., 2016). Therefore, this study aims to identify which types of material the megalithic stones in Tambunan represent through their spectral signature. The identification was conducted based on a graph comparison of the spectral signature of the megalithic stone with the spectral signature of the minerals based on a previous study.

2. EXPERIMENTAL SECTION

2.1 Location of Study

This study is conducted in the Tambunan district (refer to Figure 2). The main factor considered by researchers in choosing Tambunan as a study area is that Tambunan has many megalithic stone remains that have not been fully explored by researchers before. After the study of megalithic stones by Phelan (1997), studies related to megalithic stones in Tambunan were no longer carried out. In addition, the indigenous Kadazan Dusun people in Tambunan used to practice the tradition of megalithic stones. Therefore, Tambunan was chosen to conduct precise onsite coordinates and physical measurements of the megaliths and to examine the location of the original source of the megaliths.

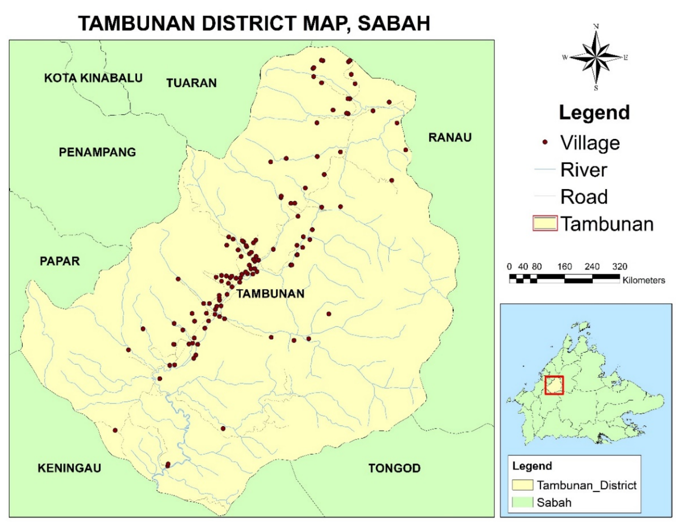

Figure 2. Location of the Study Area

2.2 Dataset and Method

In this study, Sentinel-2A satellite image data was used. This data is the choice of most researchers to conduct studies related to archeology (Abate et al., 2020; Agapiou et al., 2014). Then, the source of the megalithic stone is identified based on the spectral signature curve. The satellite image data used in this study was obtained from the Copernicus Open Access Hub website. On the website, Sentinel-2A satellite image data in the Tambunan district area is downloaded. Sentinel-2A satellite image data that is less covered by clouds was chosen to obtain a clear satellite image and facilitate the process of identifying megalithic stones. The purpose of this data is to provide a clearer image with a resolution of five meters. This resolution was chosen because it can help researchers identify megalithic stones. This Sentinel-2A satellite image display is shown in Figure 3.

Figure 3. Sentinel-2A Satellite Image

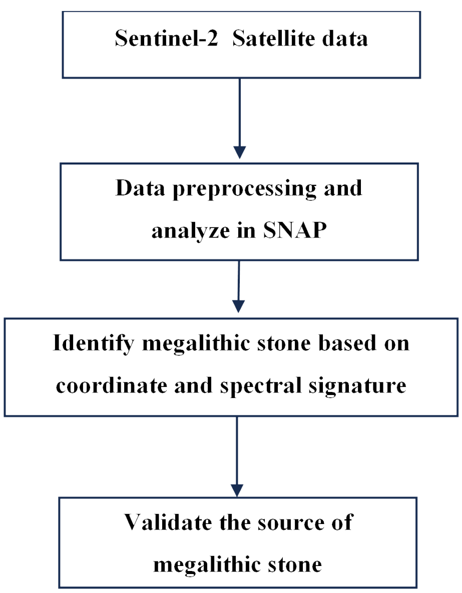

Figure 4. Study Flow Chart

The research process is carried out as shown through the flow chart in Figure 4. The megalithic stone coordinate data was first obtained from the field around the Tambunan district. Next, the coordinate data is entered into the SNAP application. Then, the identification of the spectral signature of megalithic

Figure 5. Selected Megalithic Stone Location in the Satellite Image of Tinuridung and Tinompok

stones through the spectral display in SNAP 8 is done based on the coordinates of the megalithic stones obtained. The locations of the megalithic stones involved in the satellite image are shown in Figure 5. Three stones were taken from the Tinompok area and one stone from the Tinuridung area. The SNAP 8 software will then produce a spectral display of the megalithic stones involved. Next, confirmation of the source of the stone will be done by making a spectral signature of the stones in the potential area, which is close to the river.

The validation of the data can then be conducted by making comparisons of the spectral signature between the stone and the source of the stone. This can be done by observing the curves of the graphs in the spectrum view. The type of stone needs to be identified first based on the references or guidelines provided by other researchers from previous studies, such as by Lin et al. (2019), for the megalithic stone in its current location based on the spectrum view curves. After that, the comparison of the spectrum curves between the stone and the potential source is done to see whether they are similar or not. If it is a match, then it can be said that the megalithic stone from the current location was taken from the potential source area.

3. RESULTS AND DISCUSSION

The spectral display of the resulting megalithic stones is shown in Figure 6. Each curve represents the megalithic stones selected for the spectral signature. It was found that all the curves show the same shape. Based on references from previous studies, the curves refer to mineral objects, such as Lin et al. (2019) in Figure 1.

Next, the identification of objects around the megalithic stone that have the same spectral signature, or more, is done with the megalithic stone. This step was taken because the classification process could not be carried out using the Sentinel-2A satellite image data due to the low resolution. Potential locations for the original source of megalithic stones were observed during fieldwork. The potential area of the source of the stone involves areas near the river. The display of the potential location of the megalithic stone source is shown in Figure 7. The

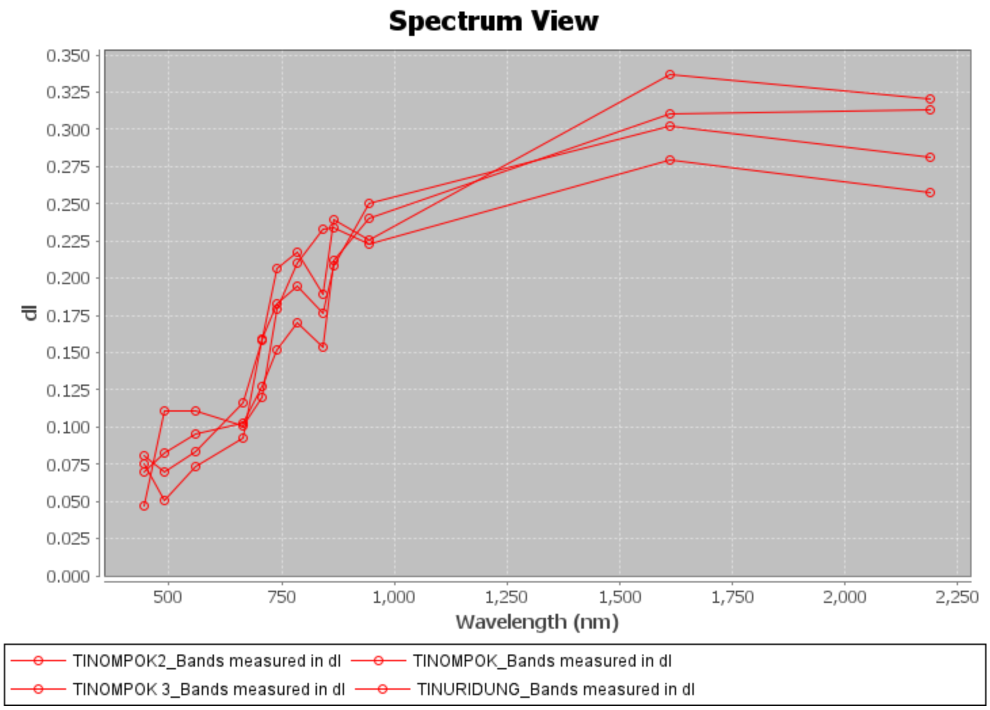

Figure 6. Spectral Signature Display of Megalithic Stones Involved

Figure 7. Display of the Location of Potential Megalithic Stone Sources (Sumber)

result of the spectral signature obtained for the stone source (Figure 8) is approximately the same as the result of the spectral signature for the megalithic stone, as shown in Figure 9.

Based on the comparison in Figure 9, although there is a difference in terms of light reflection rate measurement (dl), the shape of the spectral signature curve is almost the same. There are several factors that cause differences in terms of spectral signature light reflection for the same type of object. Among those factors are radiation detected by remote sensing through the air or space that will pass through the atmosphere. In addition, the scattering of noodles will affect long-wave radiation. Atmospheric gases such as water vapor, carbon dioxide, and ozone will absorb radiation at certain wavelengths. The amount of energy reflected by an area on earth depends on the amount of solar energy that illuminates the area and depends on the angle of incidence. If the area is uneven, the

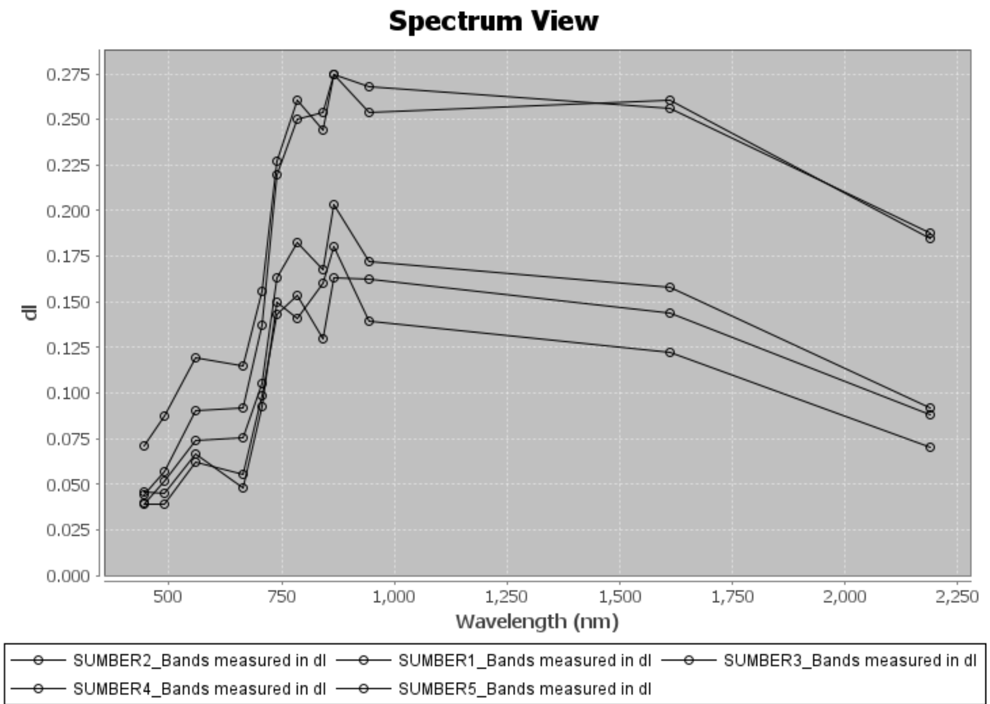

Figure 8. Spectral Signature Display of Potential Megalithic Stone Sources

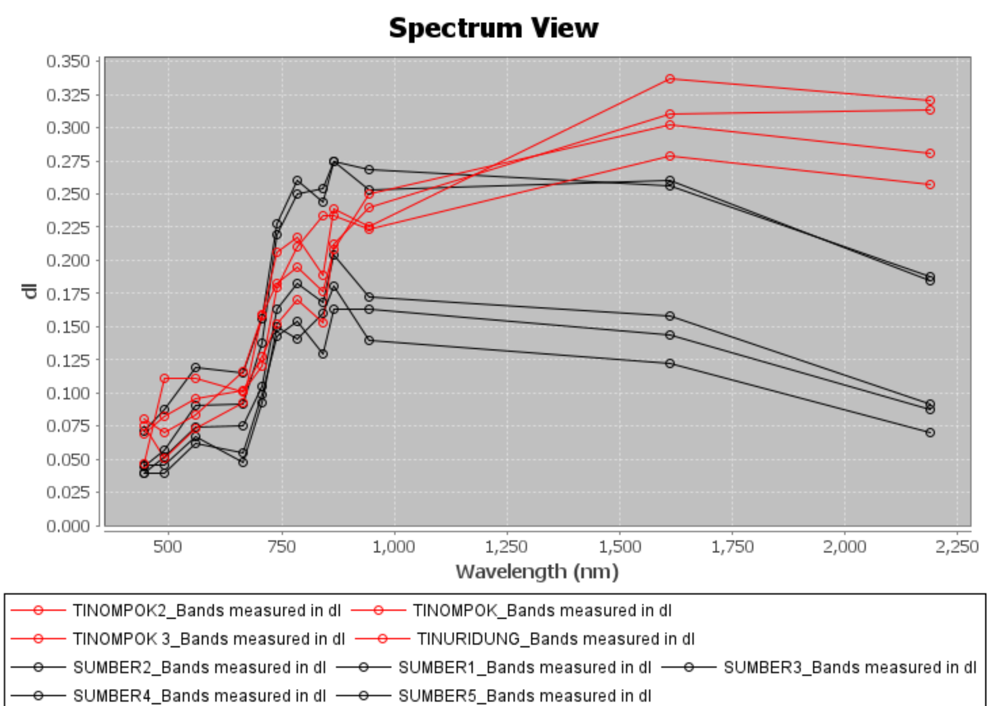

Figure 9. Comparison Displays of the Spectral Signature of Megalithic Stones (Red Line) with Potential Megalithic Stone Sources (Black Line)

energy received also changes due to the difference in the angle and direction of the slope. Finally, the amount of lighting an area receives can also be reduced by shadows. This also affects the spectral signature curve. Therefore, indeed, the megalithic stone and the sources are the same object, as the megalithic stone is positively derived from the nearby river stone. The spectral view presented in Figures 6–9 offers several distinct advantages in the context of this study. Firstly, it allows for the unique identification of materials based on their reflectance properties. By analyzing the spectral curves, we can distinguish between different types of stones, providing a clear method to identify the original sources of the megalithic stones in Tambunan. Secondly, the spectral view facilitates a direct comparison between the spectral signatures of the megalithic stones and potential source stones. This comparison is visually intuitive and highlights the similarities and differences in their spectral properties, making it easier to identify the matching source materials. Thirdly, spectral analysis is a non-destructive technique, which is crucial for archaeological studies where the preservation of artifacts is important. This method allows us to gather detailed information without physically altering or damaging the stones. Finally, the use of Sentinel-2A satellite imagery, with its high resolution, could potentially identify spectral signatures even for small-sized megalithic stones. The recommendation from this study is to improve data collection by using commercial high-resolution airborne remote sensing, such as drones equipped with hyperspectral sensors, and high-resolution spaceborne remote sensing with centimeter-level resolution. These technologies can deliver more precise results compared to the free-access data used in this study.

The results of the study show that the source of the megalithic stone is a nearby river that has large stones. Three megalithic stones were selected from Tambunan to identify their source. Among these megalithic stones are a protective stone in the village of Tinopok Liwan, a memorial oath stone in the village of Kumawanan, and a memorial stone in the village of Narayat. By using spectral signatures, similar curves were detected in which the large stones found in the river have the same spectral registration as megalithic stones. Therefore, it can be deduced that the original source of megalithic stones was the river. This is also supported by Yunus et al. (2018), who conducted a megalithic stone study in Tuaran, Sabah, and also stated that the source of megalithic stones for one of the megalithic stones is from a waterfall in the mountains. As it is known, before rivers were formed, water flowed from mountainous areas to flat land. In addition to that, Affendy Rahmat, a museum assistant from the Sabah Museum, adds to the argument by asserting that megalithic stones originate from rivers that include large-sized stones. He states that the rivers that supply the megalithic stones originate in the Crocker range, which is the source of the rivers on Sabah's west coast.

4. CONCLUSIONS

By using the spectral signature, it was found that the megalithic stone is the same as the stone at the river near the location of the megalithic stone. This result shows that the original source of the megalithic stone is a large stone from a nearby river. The spectral signature curves of megalithic stones and large stones in the river, which are more or less the same, show that the megalithic stones are actually taken from the river stones. With that, this study successfully proved that the source of megalithic stones in Tambunan originates from the river. Additionally, the use of a spectral signature can not only help the archaeologist and historian validate the story but can also assist in providing the whereabouts of the original source of the megalithic stone. All this can be done in such a short time with less manpower and economically. In this paper, the method is successfully applied to megalithic stones, but the study also indicated that the effectiveness of the method greatly depends on the type of stones in Tambunan. Thus, by applying the method to various megalithic sites in different areas or environments, the method could be extended and probably made more specific.

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