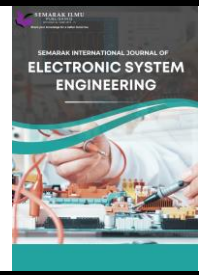




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# The Novel Method in Validating the Spectral Wavelength Optimization to Determine Archaeological Proxies by the Integration of Aerial and Ground Platforms

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### ABSTRACT

This research proposed a novel method for evaluating the ideal spectral wavelength by integrating the aerial remote sensing image and geophysical techniques to improve the detection of buried archaeological proxies via the spectral wavelength. Eight different wavelength ranges were compared to eight distinct spectral indices to conduct a more thorough vegetation analysis. The spectral information from eight various Vegetation Indices and two types of resistivity data was then analyzed using a Linear Regression model. Then, the novel "Constant Experimental Evaluation" method (CEE) was developed to improve the preliminary result. Subsequently, the results outlined newly optimal spectral wavelengths by enhancing correlation coefficient  $R^2$  values, before ( $R^2=0.595$ ) to ( $R^2=0.86$ ) after CEE application, with the spectral wavelengths values of ( $NIR_{new}=0.783\mu m$ ) and ( $Red_{new}=0.627\mu m$ ) along with the 50% of image enhancement. It suggests that the technique may be significant to any archaeological site that presents spectrally differently from its immediate environment.

## 1. Introduction

The accessibility and efficiency of technology have witnessed a revolutionary transition in recent years, providing a bewildering variety of new possibilities for finding and understanding archaeological landscapes. Researchers in archaeology and other disciplines have profited immensely by using aerial remote sensing and ground geophysical approaches in their exploration and study thanks to these advancements [1-5]. Optical imaging, thermal, and radar remote sensing instruments have all been used extensively to map and monitor archaeological sites [6,7]. Notably, images obtained by remote sensing are also constructed by using spatial, spectral, radiometric, and temporal resolutions [8-11]. Meanwhile, ground geophysical prospection has aided in cutting-edge surveys and

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studies that have expanded beyond geophysics and geology to incorporate the archaeological context at a new scale. Studies [12] have claimed that geophysical and remote sensing technologies are non-invasive, cost-effective, and offer a flexible and alternative means of exploring and defining underlying structures. For instance, combining multiple remote sensing datasets with the ground geophysical investigation has proven to be an efficient method for collecting and retrieving archaeological data. With the help of geophysical surveys, hyperspectral data, aerial photographs, and high-resolution satellite imaging have successfully explored subsurface archaeological features over the Ve'szto-Ma'gor, Tell site in Hungary [13].

Similarly, archaeological sites in southeast Kansas were also studied using a geophysical approach [14]. They analyzed Lidar data for subsurface characteristics and variables affecting soil erosion in the Middle Neosho Watershed using Electrical Resistivity Tomography (ERT) and Normalized Difference Vegetation Index (NDVI). The authors believe that the technique and analysis strategy can be implemented to detect ancient crop markings based on identifying and examining soil erosion. On the other hand, data fusion methods such as "archaeo-geophysics," which may rapidly and non-invasively detect the locations and identities of buried ancient structures, are becoming increasingly sophisticated [15].

Supplementarily, Vegetation Indices derived from multispectral remote sensing data have been studied for their potential to be used in the detection of archaeological anomalies in ancient sites [12,16-18]. Contrary to traditional remote sensing, which relies on several broadly defined spectral regions, multispectral remote sensing examines a number of precisely defined spectral channels. The use of multispectral sensors has been demonstrated for a variety of archaeological purposes, including the detection of crop stress [19-21], the differentiation of soil type and qualifying properties [22-24], the detection of chlorophyll vegetation [25,26], and the monitoring of water quality [27]. Archaeological features and their spectral signatures can be identified and determined by observing and interpreting vegetation health, i.e., spectral reflectance and proxy markers of monuments [28-30].

In Malaysia, the geophysical technique has been broadly applied in archaeology investigation. However, there is a limitation to studies utilizing the integration of both platforms. Moreover, there is no concrete indication, literature, or papers published associated with identifying specific spectra to detect the archaeological proxies in Malaysia. Hence, the study aims to validate the optimal spectral wavelength through spectra analysis by integrating aerial and ground platforms in identifying the archaeological proxies in Sungai Batu, Lembah Bujang.

## **2. Methods**

### **2.1 Area of Interest**

The Lembah Bujang is the territory of Kedah Tua, known as an ancient kingdom (Old Kedah). It is located in the northern region of the Malay Peninsula, as indicated in Figure 1. Extending a total of 144 square miles, the Muda River bounds it to the south, the Straits of Melaka to the east, the North-South Highway to the west, and the Bukit Choras to the north [31]. Geographically, the Lembah Bujang is situated near several notable features: mountains, barren hills, river valleys, and beaches [32]. The Merbok River and the Muda River nourish the Lembah Bujang. Mount Jerai, at 1300 meters in altitude, is the region's tallest peak; it is composed of shale rock and layers of mineral components, most notably quartzite [33]. Therefore, its strategic position was considered the hub of the entire archipelago. Lembah Bujang was an important administrative centre, economic hub, and port during its heyday. In the 1840s, Colonel James Low launched the archaeological research of Lembah Bujang [34]. However, FW Irby discovered the remnants of an ancient temple on Mount Jerai in 1894. The

ancient site of Lembah Bujang was the focus of this investigation. Several landowners and project developers discovered archaeological evidence associated with Lembah Bujang, a previously derelict woodland site in the Sungai Batu area. The CGAR team found signs of a sea or lake through a combination of transient electromagnetic (TEM) research and core drilling stratigraphy, as reported in [35].

The research also revealed that Sungai Batu was an important location as early as the first century CE. Only 52 of the 97 mounds planned for excavation at Sungai Batu were excavated. A total of five mounds were excavated between the years 2007 and 2010, with another fifteen mounds being uncovered in the years 2010 and 2011. Meanwhile, 32 mounds were dug during the study's second phase, which lasted from 2011 to 2021. The excavation discovered evidence of an iron smelting area (from the first century CE) and the remains of an ancient brick structure (*Candi*) from the second century CE. This finding is evidence of long-lost religious practices and rituals in the Lembah Bujang.

Moreover, the excavation team uncovered what is assumed to be a jetty, which included the remains of a roofed, tiled platform and brick platforms dating back to at least the 2<sup>nd</sup> century CE. In addition, the researchers discovered evidence of a *Syahbandar*, an administrative complex, and a warehouse area dating back to the sixth century BCE. Figure 1 depicts an overall aerial perspective of Sungai Batu.

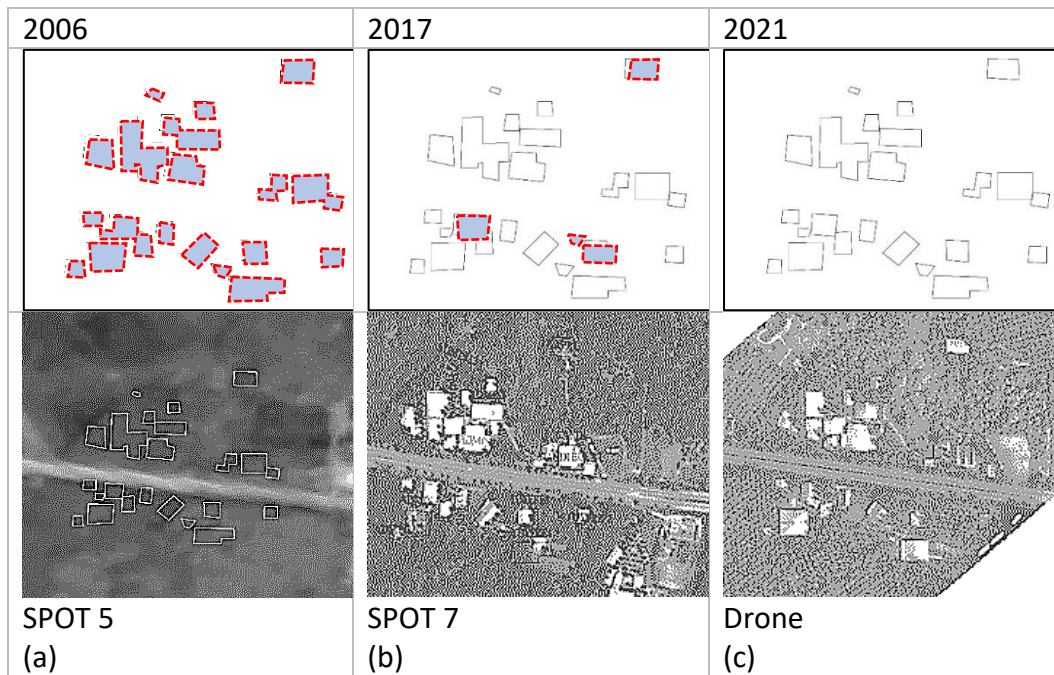


**Fig. 1.** Aerial photography of the archaeological complex of Sungai Batu (close-up image) from the DJI P4-RTK Multispectral drone image captured in March 2021

## 2.2 Tools

### 2.2.1 SPOT-5 and SPOT -7 satellite dataset

This study utilizes high-resolution SPOT-5 and SPOT-7 multispectral satellite imagery. The multi-temporal satellite photos were acquired over the Sungai Batu section of the Lembah Bujang archaeological complex in March 2006 and November 2017. The image obtained by SPOT-5 in 2006 (ARSM) shows rugged terrain. It is also reported that no archaeological excavations were conducted in the Sungai Batu region in 2006. Additionally, data collected in 2017 (SPOT-7) and 2021 (DJI P4-RTK drone) was utilized to track how the archaeological excavation phase progressed, commencing in 2007. Thus, the evolution of the Sungai Batu excavation site is depicted in Figure 2. Table 1 details SPOT-5 and SPOT-7's respective features.



**Fig. 2.** Images showed the area of Sungai Batu (a) the red-dotted polygons indicated the invisible proxies (b) The SPOT-7 satellite image reveals that the region was being excavated and that several ancient sites had been unearthed and (c) the latest image of Sungai Batu in 2021 from a drone perspective

**Table 1**

The characteristics of SPOT-5 and SPOT-7 [36]

Platform	SPOT- 5 / SPOT-7
Characteristics	Same image swath of 60 km to maintain a high level of coverage capability Resolution with 1.5 m ortho imagery Addition of a blue band to get a native natural color image
Spatial resolution	Pan: 1.5m Multispectral: 6m Colour merge: 1.5m
Spectral Bands	Multispectral bands: Blue (450 nm – 525 nm) / (0.455 $\mu$ m – 0.525 $\mu$ m), Green (530 nm – 590 nm)/ (0.530 $\mu$ m – 0.590 $\mu$ m), Red (625 nm – 695 nm)/ (0.625 $\mu$ m – 0.695 $\mu$ m), Near-Infrared (760 nm – 890 nm)/ (0.760 $\mu$ m – 0.890 $\mu$ m) Panchromatic band: Panchromatic (450 nm – 745 nm),
Swath width	60 km (2 images) 120 km with single-pass mosaic
Geolocation	35 m without GCP; < 10 m with Ref3D

### 2.2.2 Geophysical - electrical resistivity thermography

In 2017, Electrical Resistivity Tomography (ERT) was performed in the dotted red square shown in Figure 3, depicting the compound area. Two-dimensional electrical resistivity tomography (ERT) was performed using a multichannel system and the ABEM Terrameter SAS4000 instrument, commonly utilized in environmental and archaeology research by the Geophysics Unit of Universiti Sains Malaysia. Besides, an academic open-source ERT software package known as Boundless



Electrical Resistivity Tomography (BERT) was used to carry out the 2D inversion technique, and irregular triangular meshes were utilized [15]. Table 2 summarizes the features of the ground geophysical (ERT) method used to locate underground features in Sungai Batu.



**Fig. 3.** The SPOT-7 satellite image captures the preliminary research region of Sungai Batu, Lembah Bujang. The red square box denotes the geophysical measuring area (electrical resistivity technique)

**Table 2**

The characteristic of Electric Resistivity Thermography (ERT) in identifying the subsurface features in Sungai Batu, Lembah Bujang [37]

Characteristic	Geophysical
Medium	Electrical Resistivity Thermography.
Year	2017
Accuracy	Depending on the method (Pole-pole < low accuracy) Pole-dipole > good accuracy) Dipole-dipole > high accuracy and detail profile)
Spectral Range	Electric wave
Spatial Extend	Several hectares (Vertical)
3D visualization	Available
Soil penetration	Available
Type information	Point

### 3. Solution Method and Algorithm

Based on the holistic scheme of the proposed technique depicted in Figure 4, the preliminary process comprises the following operation. Radiometric and atmospheric corrections and co-registration were applied during pre-processing to rectify the data. In order to conduct a more comprehensive analysis of vegetation, eight spectral indices were used. Each indication assists an archaeology detection analysis in its unique way, as in Table 3. Each indicator uses a different set of algorithms and constraints to expose different characteristics of the vegetation. Eight different groups of wavelength ranges were evaluated based on the spectral reflectance analysis results. These included the Archaeological Index (AI) [38], a Proposed Spectral 1 (PS-1), Proposed Spectral 2 (PS-2),

and Proposed Spectral 3 (PS-3), additional spectral of ancient properties such as Iron, Granite, and Brick [39], as well as wavelengths Spectral studied by Sarris [13]. These bands were determined to be optimal for plant growth by measuring their reflectance across a broad spectrum [26,40,41]. Measurements of Red and Near-Infrared reflectance are the basis for most Vegetation Index (VI) algorithms. Other indices' algorithms, such as GNDVI and EVI, use a Green and/or Blue color wavelength that is both an element of the spectrum and very Near-Infrared (NIR) [42,43]. This is in contrast to what was mentioned previously.

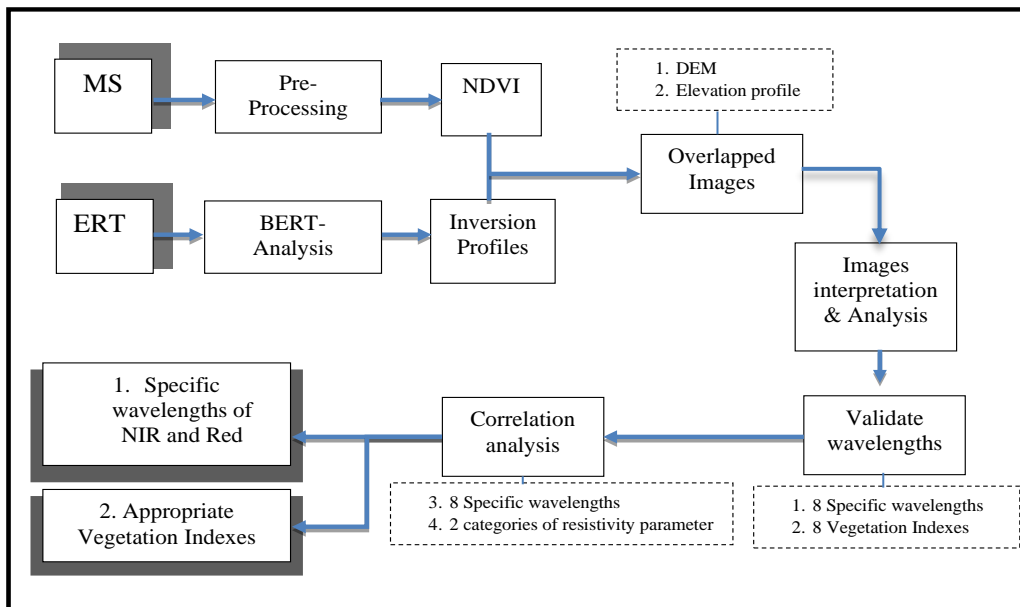


Fig. 4. Illustrative flow chart representation to validate the preliminary specific wavelength of archaeological proxies

Table 3

Indication of the calculation for determining the specific wavelengths between eight Vegetation Indexes and eight groups of selected spectral

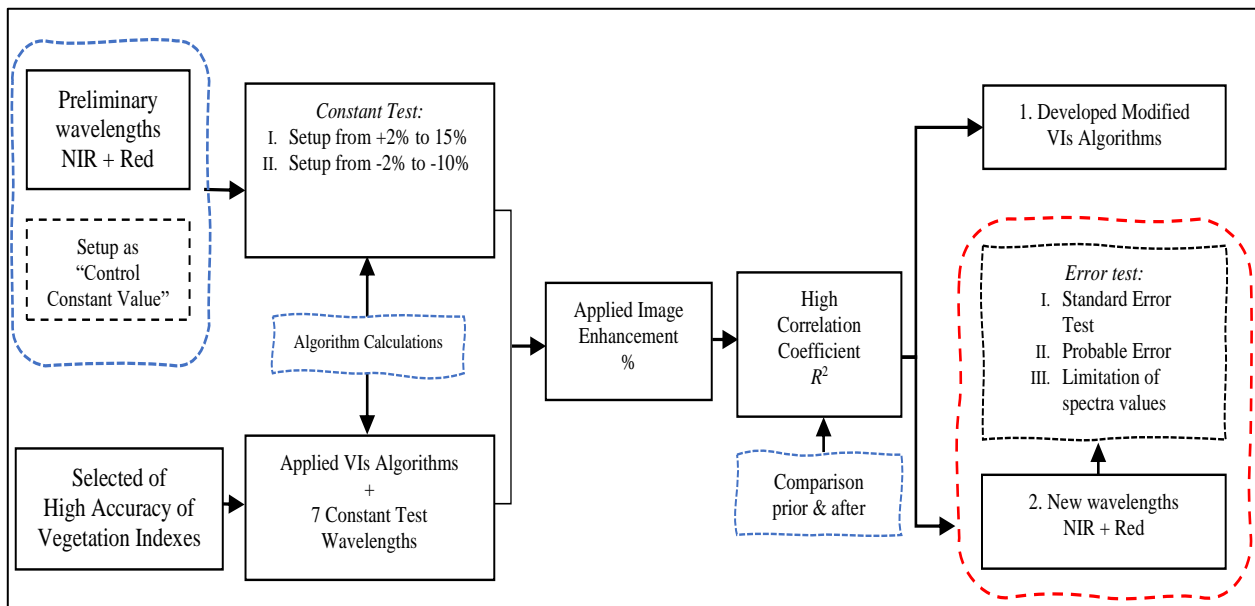
	Wavelength	AI	PS-1	PS-2	PS-3	Iron	Granite	Brick	Sarris et. al
	NIR	0.8	0.825	0.9	0.760	0.935	0.968	0.947	0.9
	Red	0.7	0.66	0.67	0.640	0.7	0.7	0.7	0.69
Algorithm									
NDVI									
GNDVI									
SR									
MSR									
DVI									
RDVI									
EVI									
MSAVI									

Next, the values of the spectra for each index and resistivity were averaged ( $\bar{x}$ ) and ( $\bar{y}$ ). Specifically, the  $y$  value was determined from the resistivity indicator's value range. Finally, the parameter values for  $x$  and  $y$  will be used to calculate the  $R$  values for each of the eight indices (NDVI, GNDVI, SR, MSR, DVI, RDVI, EVI, and MSAVI) against the Resistivity of the Ancient River (RAR) and resistivity of buried properties (RBP) were using the formula as in Equation (1) and the result discussed in section result and discussion.

$$r = \frac{\Sigma(x - \bar{x}) - (y - \bar{y})}{\sqrt{\Sigma(x - \bar{x})^2 \Sigma(y - \bar{y})^2}} \quad (1)$$

### 3.1 New Method: Constant Experimental Evaluation

The "Constant Experimental Evaluation" (CEE) is developed further to emphasize the originality of the research. Based on the hypothesis, this technique seeks to answer whether NIR and RED wavelengths yield correct data, to begin with, or to what extent applying a new CEE method to these numbers improves their precision. In order to determine the optimal wavelengths, it is suggested that percentage increases and decreases should be used in an experimental setting. However, the maximum and minimum levels of the NIR and Red ranges must be considered when deciding on an increase or decrease in value. To overcome these limitations and achieve optimal results from the VIs algorithms, the existing linear regression technique must be modified by performing several calculations, with the percentage value indicating image optimization. The *r*-squared values derived from the spectral values will be generated afterwards via linear regression. Finally, the optimal spectral wavelength to detect the archaeological proxies in Sungai Batu will be obtaining new optimal wavelengths of NIR<sub>new</sub> and Red<sub>new</sub> with the improvement in accuracy value along with the percentage of image augmentation. The overall idea is illustrated in the flow chart below (see Figure 5).



**Fig. 5.** Flowchart illustrating the validation of the particular wavelength of archaeological proxies using the CEE approach

## 4. Results and Discussion

### 4.1 Preliminary Optimal Spectral Wavelength

In order to figure out the relationship between spectral Vegetation Indexes (VIs) and ERTs and to confirm the preliminary specific wavelengths of proxies, statistical analysis was used. The correlation coefficient (*r*) was utilized to compare the different correlations between several VIs with a specific spectral wavelength of  $\rho$ NIR  $\mu$ m and  $\rho$ Red  $\mu$ m against the resistivity data. All indices, NDVI, GNDVI, SR, MSR, DVI, RDVI, EVI, and MSAVI, were then calculated as a mean value ( $\bar{x}$ ). Next, two separate resistivity data of Buried Properties (BRP) and Ancient River (RAR) were also calculated as a mean

value ( $\bar{\gamma}$ ) for the  $r$  calculation. All BRP and RAR resistivity readings were purposefully selected from the resistivity indicator's range of values. The ranges of 1312.5  $\Omega$ -m to 3500  $\Omega$ -m and 21.25  $\Omega$ -m to 100  $\Omega$ -m are used as decision parameters for BRP and RAR, respectively. Table 4 displayed the comprehensive analysis for additional summative results. The median spectral results benchmark the preliminary wavelength values in determining the ideal spectral wavelengths. Therefore, the most significant spectral wavelength is Proposed Spectral 1 (PS-1), which ranges from NIR=0.825 $\mu$ m to Red=0.66 $\mu$ m and is relatively close to the median spectral result for each VIs sample.

**Table 4**  
 Result of the VI algorithms with a specific wavelength and spectral median of each index

Algorithms	Wavelength (nm)	AI (Agapiou et al., 2012)	PS- 1	PS- 2	PS- 3	Iron	Granite	Brick	Sarris et al. (2013)	Spectral Med.
	NIR	0.8	0.825	0.9	0.760	0.935	0.968	0.947	0.9	
	Red	0.7	0.66	0.67	0.640	0.7	0.7	0.7	0.69	
NDVI		0.067	0.111	0.146	0.086	0.144	0.161	0.150	0.132	0.125
GNDVI		0.19	0.2	0.241	0.16	0.26	0.275	0.265	0.24	0.229
SR		1.143	1.25	1.343	1.188	1.336	1.383	1.353	1.304	1.288
MSR		0.478	0.44	0.438	0.433	0.458	0.453	0.456	0.455	0.457
DVI		0.1	0.165	0.23	0.12	0.235	0.268	0.247	0.21	0.197
RDVI		0.082	0.135	0.184	0.10	0.184	0.208	0.193	0.167	0.156
EVI		0.448	1.01	1.06	1.33	0.77	0.84	0.8	0.789	0.881
MSAVI		3.35	-3.81	-4.44	-3.3	-4.64	-4.91	-4.73	-4.36	-4.193

**Abbreviations:** NDVI = Normalised Difference Vegetation Indices, GNDVI = Green Normalised Difference Vegetation Indices, SR = Simple Ratio, MSR = Modified Simple Ratio, DVI = Difference Vegetation Index, RDVI = Renormalized Difference Vegetation Index, EVI = Enhanced Vegetation Index, MSAVI = Modified Soil Adjusted Vegetation Index.

Subsequently, eight VIs algorithms were evaluated against two resistivity value ranges (RAR and BRP) to find out which Vegetation Indexes are associated (interrelated) with the ERTs data. The respective values of higher correlations were colored indicated as in a) green: relatively strong positive correlation, b) blue: relatively strong negative correlation, and c) grey: relatively weak correlation.




Table 5 shows that the results show that almost all of the indices have a high correlation between VI algorithms and resistivity for RAR. The DVI and RDVI show a high positive correlation with RAR ( $r = 0.94$ ) and RBP ( $r = 0.95$ ). In identifying buried archaeological properties, MSAVI has a strong negative connection with RAR ( $r = -0.93$ ) and RBP ( $r = -0.95$ ). In contrast, NDVI for resistivity data over the (RAR) test had the lowest correlation with RAR ( $r = 0.66$ ), indicating that the NDVI algorithm is less suited for detecting underground water than archaeologically buried structures or materials. Additional research [1,44,45] confirms that the Normalized Difference Water Index (NDWI) algorithm is more successful when applied to water from the subsurface or underground. Thus, the study demonstrated that NDVI-RBP is more highly correlated ( $r = 0.95$ ) than NDVI-RAR.



**Table 5**

Result of the correlation coefficient (*r*) with a range of -1 for each vegetation index and each type of resistivity data for the ancient river and buried properties

	NDVI	GNDVI	SR	MSR	DVI	RDVI	EVI	MSAVI	RAR	RBP
	0.067	0.19	1.143	0.478	0.1	0.082	0.448	-3.35	21.25	1312.5
	0.111	0.2	1.25	0.44	0.165	0.135	1.01	-3.81	32.5	1625
	0.146	0.241	1.343	0.438	0.23	0.184	1.06	-4.44	43.75	1937.5
	0.086	0.16	1.188	0.433	0.12	0.10	1.33	-3.3	55	2250
	0.144	0.26	1.336	0.458	0.235	0.184	0.77	-4.64	66.25	2562.5
	0.161	0.275	1.383	0.453	0.268	0.208	0.84	-4.91	77.5	2875
	0.150	0.265	1.353	0.456	0.247	0.193	0.8	-4.73	88.25	3187.5
	0.132	0.24	1.304	0.455	0.21	0.167	0.789	-4.36	100	3500
Mean	0.067	0.16	1.143	0.433	0.1	0.082	0.448	-4.91	1312.5	21.25
RARr	0.66	0.82	0.92	0.90	0.94	0.94	0.87	-0.93		
RBPr	0.95	0.94	0.93	0.92	0.95	0.95	0.88	-0.95		

-  Relative strong+ve correlation
-  Relative strong-ve correlation
-  Relative low correlation

**Abbreviations:** **NDVI** = Normalised Difference Vegetation Indices, **GNDVI** = Green Normalised Difference Vegetation Indices, **SR** = Simple Ratio, **rSR** = Reverse Simple Ratio, **MSR** = Modified Simple Ratio, **DVI** = Difference Vegetation Index, **RDVI** = Renormalized Difference Vegetation Index, **EVI** = Enhanced Vegetation Index, **MSAVI** = Modified Soil Adjusted Vegetation Index, **RAR** = Existing result of Resistivity; Ancient River, **RBP** = Existing result of Resistivity; Buried Properties.

#### 4.2 Novelty of the CEE method

Table 6 shows the initial spectral median correlation value (*r*) from the combination of (NDVI =0.111), (DVI=0.165), (RDVI=0.135), and (MSAVI=-3.81). Consequently, alterations were made to the four significant VIs algorithms using the CEE approach by continuously increasing and reducing percentages from the initial NIR=0.825 and Red=0.66 wavelength values. Furthermore, these initial wavelength values are referred to as "Control Constant Values" (as shown in the blue square box). The wavelengths that have a probability of achieving a "very strong" value of *R* more significant than the "Constant Control Value, *R* = 0.595," is determined by adding and subtracting constant percentages of 2%, 5%, 10%, and 15%, respectively. Since Red's peak spectral range is only 0.700µm, the maximum percentage increase is capped at 15%. However, due to the fact that the NIR minimum range is more than 0.760µm before approaching the Red-Edge wavelength zone, the maximum percentage reduction is set at 10%. Four percentage groups were analyzed for each method to discover which spectral wavelengths and percentages are optimal for recognizing archaeological characteristics and calculated as "Percentage Image Enhancement Values" (%IE). A sequence of percentages ranging from 20% through 50%, 80%, and 95% was used to compute the percentage.

**Table 6**

Results using the method of "Constant Experiment Evaluation" (CEE) through four significant Vegetation Indexes and "Control Constant Value" of NIR and Red to validate the specific wavelengths in determining archaeological proxies

	NIR RED	% Image Enhancement (%IE)	NDVI (%IE)	* DVI (%IE)	* RDVI (%IE)	* MSAVI (%IE)	* R <sup>2</sup>
Control constant	0.825 0.66	-	0.111	0.165	0.135	3.81	0.595
+15%	0.949 0.759	95	0.105	0.181	0.138	0.261	0.662
		80	0.088	0.152	0.116	0.22	0.661
		50	0.055	0.095	0.073	0.138	0.667
		20	0.022	0.038	0.029	0.055	0.661
+10	0.908 0.726	95	0.105	0.216	0.162	0.129	0.002
		80	0.089	0.182	0.140	0.109	0.003
		50	0.055	0.114	0.085	0.068	0.002
		20	0.022	0.046	0.034	0.027	0.001
+5%	0.866 0.693	95	0.105	0.164	0.132	0.126	0.027
		80	0.089	0.138	0.111	0.106	0.023
		50	0.055	0.865	0.069	0.067	0.060
		20	0.022	0.035	0.028	0.027	0.033
+2%	0.842 0.673	95	0.106	0.161	0.130	0.126	0.027
		80	0.090	0.135	0.110	0.106	0.025
		50	0.050	0.084	0.069	0.067	0.041
		20	0.022	0.034	0.027	0.027	0.044
-10%	0.756 0.594	95	0.105	0.142	0.119	0.073	0.353
		80	0.089	0.119	0.100	0.062	0.294
		50	0.055	0.075	0.063	0.039	0.278
		20	0.022	0.03	0.025	0.016	0.272
-5%	0.783 0.627	95	0.105	0.148	0.124	0.243	0.676
		80	0.089	0.125	0.105	0.205	0.677
		50	0.056	0.078	0.08	0.128	0.860
		20	0.022	0.031	0.026	0.051	0.672
-2%	0.809 0.647	95	0.105	0.154	0.744	0.247	0.1995
		80	0.089	0.130	0.626	0.208	0.200
		50	0.0555	0.081	0.392	0.130	0.200
		20	0.0222	0.032	0.157	0.052	0.199

Consequently, the CEE experiment test results demonstrated that the spectral wavelengths with decreasing values of -5% and 50% image enhancement had a greater R<sup>2</sup> value accuracy than the "control constant value" R<sup>2</sup> result, as given in Table 6, which is highlighted in the red square box. With the improved spectral wavelengths values of (NIR<sub>new</sub>=0.783m) and (Red<sub>new</sub>=0.627m) and the 50% of

image enhancement, the linear regression graph, as presented in Figure 6, shows that the new value of  $R^2_{new}$  is 0.86, which is approximately higher than the previous value of ( $R^2=0.595$ ). These significant values may be used as a future reference to determine archaeological proxies in Sungai Batu. The following Equations (2) to Equations (5) describe how this method improved pre-existing techniques across all four VIs. Lastly,  $R$  must be greater than six times the Probable Error ( $6PEr$ ). Clearly, the  $R$ -value is greater than  $6PEr$ , indicating a statistically significant correlation.

Modified Vegetation Indexes algorithms;

$$NDVI_{modified} = \frac{(NIR - RED)}{(NIR + RED)} \times \frac{1}{2} \quad (2)$$

$$DVI_{modified} = \frac{(NIR - RED)}{2} \quad (3)$$

$$RDVI_{modified} = \frac{(NIR - RED)}{(NIR + RED)^{0.5}} \times \frac{1}{2} \quad (4)$$

$$MSAVI_{modified} = \frac{2NIR + 1 [(2NIR + 1)^2 - 8(NIR - RED)]^{0.5}}{4} \quad (5)$$

Lastly, the  $R^2=0.86$  value was tested with The Standard Error Test to cross-check the value of  $R$  is a significant correlation or low correlation.

**Standard Error Test;**

$n = 28, \quad R = 0.927$

Here  $n$  is a total variable number of calculations as shown in Table 6, and  $R$  represents a value of  $R^2$ . Next, these values are calculated using Equation (6), called Standard Error Test ( $SEt$ ), followed by Probable Error Test ( $PEt$ ), as shown in Equations (7)-(8).

i) *Standard error of R*

$$SEr = s = \frac{(1 - 0.927^2)}{\sqrt{28}} = 0.026 \quad (6)$$

ii) *Probable Error*

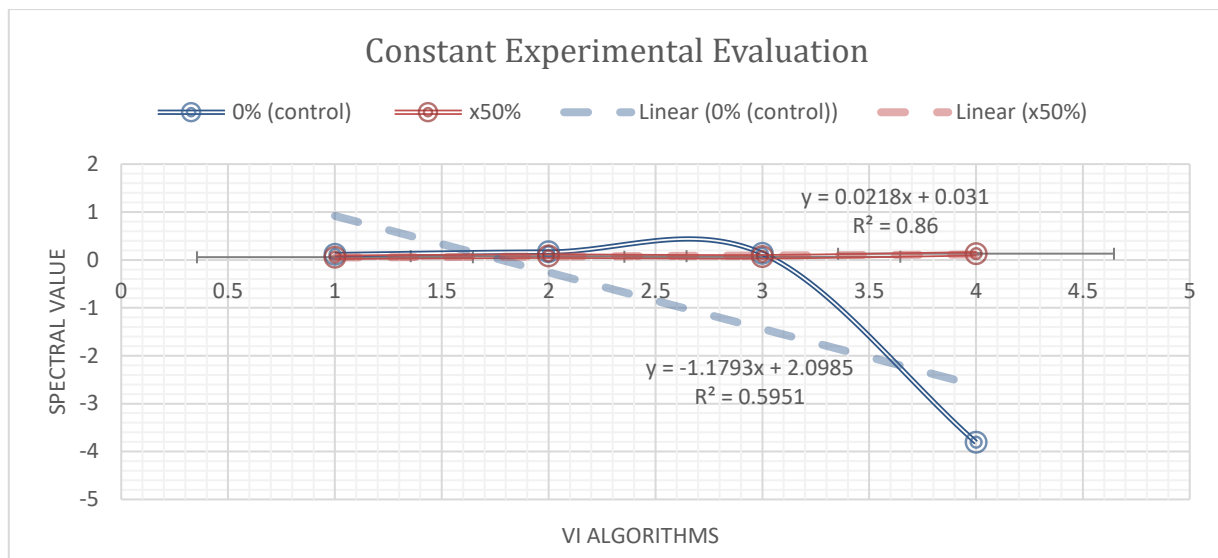
$$PEr = 0.6745 * \frac{(1 - r^2)}{\sqrt{n}} \quad (7)$$

$PEr = 0.0175$

iii) *The limit of the spectral value of R;*

$R > 6PEr \quad (8)$

$6PEr = 6 (0.0175) = 0.105 = \mathbf{0.927 > 0.105}$



**Fig. 6.** Spectral plot of four VIs algorithms (NDVI, DVI, RDVI, and MSAVI) by comparing the  $R^2$  values before and after applying the CEE method

## 5. Conclusions

In order to evaluate the appropriate spectral wavelengths for detecting archaeological proxies within the context of Malaysia's climate and vegetation heterogeneity, this research proposed a novel methodology by creating the "Constant Experimental Evaluation" (CEE) method. The first novel method used the Pearson correlation coefficient to validate the association between eight Vegetation Indices and Electrical Resistivity Thermography data measurements. The new CEE technique was then used to verify the preliminary results at particular wavelengths. According to the results of the first technique, the optimal spectral wavelengths are ( $NIR_{new}=0.783\mu m$ ) and ( $Red_{new}=0.627\mu m$ ), and 50% of image enhancement is achieved with an improvement in the correlation of 0.86 rather than 0.595. It has been found that the NDVI, DVI, RDVI, and MSAVI are the four Vegetation Indices that have the strongest correlation with the resistivity approach region. The remaining four suggested vegetation indices are moderately correlated. Future research will be expanded to determine the optimal spectral band and characterize the spectral patterns of the archaeological features, particularly in Malaysia's heterogeneous climate and vegetation.

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