PREDICTIVE MODELING OF CAVE SETTLEMENTS IN KARST AREA OF KAPUAS BASIN, WEST KALIMANTAN

Predictive Modeling Gua Hunian di Kawasan Karst Cekungan Kapuas, Kalimantan Barat

Ni Luh Gde Dyah Mega Hafsari[1], Vida Pervaya Rusianti Kusmartono[2], and M. Wishnu Wibisono[3]

[1]Faculty of Archaeology, Leiden University, Netherlands
[2]Research Center for Prehistoric and History Archaeology, BRIN, Indonesia
[3]University of Gadjah Mada. Yogyakarta, Indonesia
ni.luh.gde.dyah.mega.hafsari@umail.leidenuniv.nl

Manuscript received : 10 February 2023
Manuscript revised : 12 February 2023
Manuscript accepted : 15 February 2023

Abstract. *Starting in the 1970s, the captivating archaeological potency in the tropical rainforest area of West Kalimantan started to be revealed. Since then, several expeditions and research had been conducted by The National Research Center for Archaeology and Archaeology Office in South Kalimantan. One of them was an exploration and excavation led by Vida P.R. Kusmartono from 2013-2019. Previous studies have shown that the area of Upper Kapuas Basin possesses numerous archaeological resources, however, many of the areas remain uncovered. This condition is caused by the extensiveness and difficulty of this area to be reached. For that reason, in 2020, we created a predictive model to give an overview of the probability of archaeological caves in this area. This predictive model uses environmental variables and is based on the hypothesis of the environmental resources variables in choosing cave settlements in the prehistory era. The variables used are the elevation of the valley, the proximity distance from the water source, the steepness of the slope, the direction of the slope, and the lineament density. Analysis of the variable elevation of the valley, proximity distance from the water source, and the steepness of the slope produced a map of accessibility. This map was then integrated with the lineament density variable and considered the direction of the slope to produce a map of potential areas for cave settlements.*

Keywords: *Predictive Model, Tropical Rainforest, Upper Kapuas Basin, Cave Settlement*

Abstrak. Sejak tahun 1970-an, daya tarik dan potensi arkeologi di kawasan hutan hujan tropis Kalimantan Barat mulai terungkap. Sejak saat itu, beberapa ekspedisi dan penelitian telah dilakukan baik oleh Pusat Penelitian Arkeologi Nasional, maupun Balai Arkeologi Kalimantan Selatan. Seperti yang dilakukan oleh tim yang dipimpin Vida P. R. Kusmartono pada tahun 2019, kegiatan eksplorasi dan ekskavasi telah dilakukan di kawasan karst Cekungan Kapuas, Kapuas Hulu. Meskipun demikian, situs hunian manusia prasejarah di kawasan ini belum semuanya teridentifikasi. Hal ini disebabkan luasnya cakupan dan beratnya medan penelitian di wilayah kawasan karst tersebut. Oleh karena itu, pada tahun 2020 telah disusun sebuah predictive model untuk memberikan gambaran akan probabilitas potensi gua hunian di kawasan ini. Predictive model ini menggunakan beberapa variabel lingkungan dan didasari atas hipotesa pengaruh kondisi sumber daya alam terhadap pemilihan lokasi hunian pada masa prasejarah. Variabel yang digunakan yaitu ketinggian lembah, jarak dari sumber air, kemiringan lereng, arah hadap lereng, dan kepadatan kelurusan. Analisis terhadap variabel ketinggian lembah, jarak dari sumber air, dan kemiringan lereng menghasilkan peta kelas aksesibilitas. Peta ini kemudian diintegrasikan dengan variabel kepadatan kelurusan serta melihat pengaruh arah hadap lereng menghasilkan peta yang menunjukkan probabilitas area dengan potensi gua hunian.

Kata kunci: Predictive Model, Hutan Hujan Tropis, Cekungan Kapuas, Gua Hunian

1. Introduction

The landscape of Kapuas Basin, Kapuas Hulu, was formed during the Jurassic and Cretaceous/Cretaceous periods in the mid to late Mesozoic Era between 201-56 million years ago. This makes the Kapuas Basin landscape much older than the areas in East and South Kalimantan which were only formed in the Cenozoic Era in the Paleogene period of the Late Eocene about 40 million years ago (Burton-Johnson 2013). It can be said that the Kapuas Hulu region was formed long before the entire island of Borneo that we know today emerged to the sea surface. This makes the Kapuas Hulu area one of the oldest areas on the mainland of Kalimantan.

The research area is a karst ecosystem, where karstification occurs in thick and pure limestone originating from one or along a joint or fault lineament. The exokarst landform that stands out from the research area is the formation of karst hills that rose high to form karst towers with very steep slopes and separated by Hovorit, Bulit and Bungan rivers or alluvial land. The karstification process also occurs in endokarst, resulting in an underground river and its ornaments forming a cave system (V. P. Kusmartono, et al. 2019).

In 1984, the Nanga Balang site was excavated by the National Research Center for Archaeology, and in 2008 by the Archaeology Office in South Kalimantan (Anggraeni, et al. 1992); and (Kusmartono, Sunarningsih, et al. 2008). The dating resulted from the analysis of charcoal samples and excavation finds concluded that Nanga Balang is a Neolithic site that was inhabited around 3000-2500 years ago, and possibly up to the Bronze Age (Simanjuntak 2002).

In the 1960s, the Nanga Balang site was used as a location for the Bukat ethnic settlement of about 250 Bukat people (Kusmartono, Sunarningsih, et al. 2008). Currently, the main subsistence of the Bukat ethnic group is gold panning, interspersed with cucumber, sweet potato, and dry rice farming activities (Hindarto, Kusmartono, and Herwanto 2018). These farming fields can be found across the Kapuas River, and stretch for 2 km from the river bank.

About 20 km upstream of the Kapuas River, east of Nanga Balang, lies the Diang

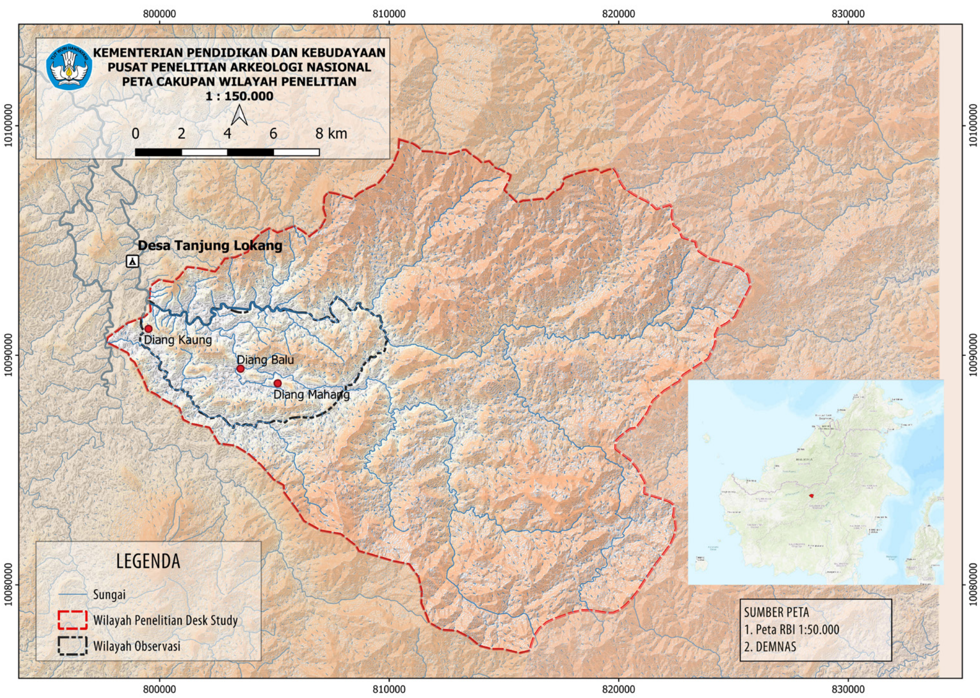

Figure 1. Map of study area
(Source: Hafsari, Kusmartono, Wibisono)

Kaung rock shelter. Diang Kaung rock shelter can be reached from Putussibau in 12 hours by river boat, and only during the dry to rainy season transition period (or vice versa) when the water level is sufficient to navigate the boat. In a 1989 speleological study, Luc-Henri Fage saw charcoal drawings of symbolic figures on the ceiling of the Diang Kaung. In 1992, Chazine surveyed the Diang Kaung and found numerous pottery shreds on the cave floor. The charcoal sample (S-ANU 8570) that he sent to the radiocarbon laboratory at the Australian National University (ANU) showed it dated around 3613-2779 years cal.BP (Fage and Chazine 2010); (Plutniak, et al. 2014). This chronology is very similar to the dating of the Nanga Balang site, which indicates the presence of humans in Diang Kaung around 3000 years ago.

From 2013-2019, the Archaeology Office in South Kalimantan and National Research Center for Archaeology (Pusat Penelitian Arkeologi Nasional/Arkenas) excavated three caves in this area, namely Diang Kaung, Diang Balu, and Diang Mahang (shown in Fig. 1). The excavation found lithic artifacts, pottery sherds, faunal remains of both vertebrates and invertebrates, as well as several caves with rock art. The dating of the charcoal samples found in Diang Kaung and Diang Balu indicated settlement activity that lasted up to 15,000 years ago (Kusmartono, Hindarto and Herwanto, 2017) (Hindarto, Kusmartono, and Herwanto 2018) (V. P. Kusmartono, et al. 2019).

Although several studies have been done, prehistoric human settlement in the karst area of the Kapuas Basin has not yet been identified. This condition is due to the great range and difficulty of this area. The discovery of archaeological sites will help to determine the characteristics of occupation and the development of prehistoric culture in the karst area of the Kapuas Basin. To overcome this problem, a predictive model is needed to make survey activities more efficient. This predictive model is the result of an analysis of environmental variables to produce a potential location of prehistoric cave settlements. This is based on the hypothesis of the influence of natural resources as supporting variables for the selection of prehistoric settlement locations.

Yaworsky et. al. (2020) mentioned the importance of predictive models both in archaeological research and in cultural resource management. Predictive models are central to both archaeological research and cultural resource management (Yaworsky, et al. 2020). Archaeological predictive modeling is the practice of building models that in some way, indicates the likelihood of archaeological sites, cultural resources, or past landscape use across a region (Mink, Pollack, and Stokes 2006).

The difficulty to access this research area also affects the efficiency of research capital. Research capital can be seen in the form of human resources that are experts in the research focus, the availability of the research budget, and the duration of the research. This predictive model is needed as guidance to conduct a more time and resource-efficient field survey. From this understanding, here we show a predictive model that had been created to determine areas with potential cave settlements in the karst area of Kapuas Basin (Müller Mountains).

2. Methods

Butzer (1982) in Archeology as Human Ecology stated that the environment is the determining factor for humans to choose the location of settlements. There are several variables related to environmental conditions that can the potential to be chosen as a settlement location, including the availability of water resources, the presence of shelter, pleasant soil conditions in the sense that it is not wet or humid, the availability of food supplies, as well as the presence of additional elements such as marine animals or other animals. Moving on from that thought, this predictive model was composed using several adaptable variables, which are the elevation of the valley, proximity distance to the water source, steepness of the slope, and direction of the slope.

The data used are data of water sources, lineament density, and DEM (Digital Elevation Model). Water source data is in the form of river polygon and lake or lake polygon data on the RBI (Indonesian Rupa Bumi) map, while spatial data is in the form of administrative boundaries. Data of administrative boundaries purposedly used to ease administrative matters of the research and provide a more stable boundary of the research area in the long run. Some spatial data is obtained from the RBI on the website https://tanahair.indonesia.go.id. The DEM data used is DEMNAS with a spatial resolution of 8 meters (obtained from http://tides.big.go.id/DEMNAS/). In addition, river data issued by the Geospatial Information Agency with a scale of 1:50.000 is also used. Data analysis and maps of environmental variables were created using ArcGIS 10.2 software.

The mapping of environmental variables produced a map of the class of the valley elevation, a map of the class of proximity distance to the water source, a map of the class of steepness of the slopes, a map of the direction of the slopes, and a map of lineament density. The map of the class of the valley elevation, the map of the class of proximity distance to the water source, and the map of the class of steepness of the slopes were synthesized by weighting to produce a map of the class of accessibility. Furthermore, this map of the class of accessibility is combined with a map of lineament density and was considering the direction of the slopes to produce a predictive model map that shows the probability of areas with potential cave settlements, like shown in Fig. 2.

Case studies were also carried out on the resulting predictive model. The positions of the three caves that have been excavated in 2013-2019 (Diang Balu, Diang Kaung, and Diang Mahang) will be seen in the predictive model map to provide a further description of the potential and probability of other archaeological caves in the area.

3. The Mapping of Environmental Variables

The determinants of the settlement locations poured into environmental variables that are used to see the areas that have the most potential to become prehistoric cave

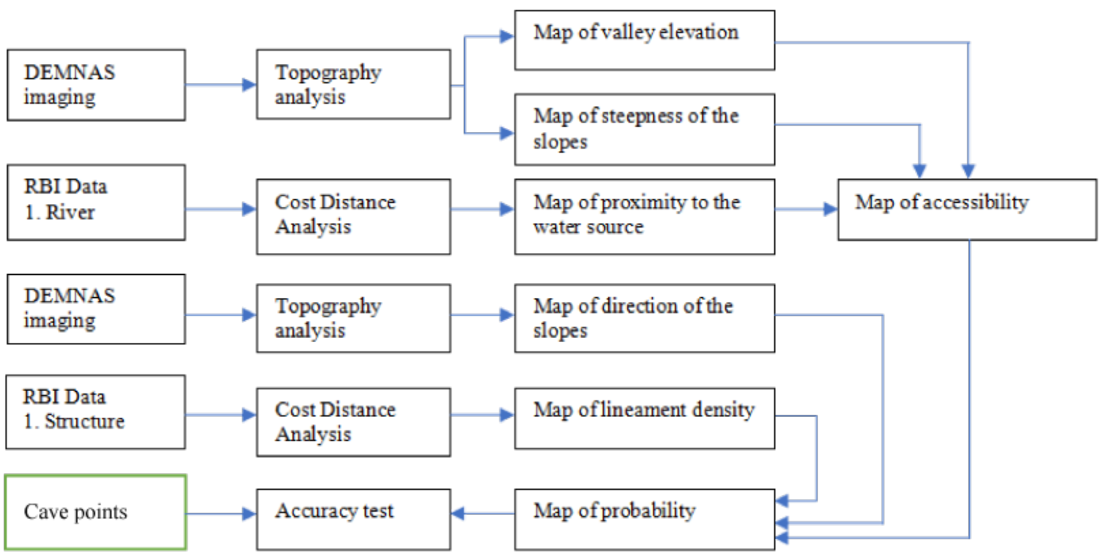

Figure 2. Mapping proccess flowchart
(Source: Hafsari, Kusmartono, Wibisono 2021)

settlements in the karst area in the Hovorit river line, Kapuas Hulu, West Kalimantan. The maps resulting from this study are as follows.

3.1 Map of the Class of Valley Elevation

Prehistoric cave settlements usually are caves with advanced formations and are generally located far high from the valley. Several archaeological studies provide a classification that as a settlement, prehistoric caves have several conditions, one of which is the level of ease in reaching the caves.

This variable produced a map based on calculations of the valley elevation in the research area. This variable is classified into five classes with a value of 1-5. The further the distance between the area and the valley network, the lower the value. Class determination is based on the range of distance figures from the valley network, which is 0-442 m. A class with a value of 5 is given to areas with a valley network distance between 0-90m, which is in the "very close" category. A class with a value of 4 is given to areas with a valley network distance between 91-180m, which is a "close" category. While the "moderate" category is given to the valley network with a distance between 181-270m with a value of 3. The "far" category is given to the distance to the valley network between 271-360m with a value of 2, and the value of 1 is given to the valley network in the "very far" category with a distance between 361-442m. Figure 3 shows that the closer an area is to the valley network, the color on the map is green, while the further away from the valley network the color on the map changes to red gradually.

Table 1 shows the area percentage based on the variable distance from the valley. These percentages indicate that the position of the area with a distance from the valley of 91-180m or class with a value of 4 is the largest area with 13,764.44Ha or 38.72% of the total area of study. Followed by class with a value of 5 with 11,011.42Ha or 30.92% of the total area. It is showing that the majority of the area of study has a short distance from the valley network.

Table 1. Area Percentage for Variable Distance from the Valley

Distance (meter)	Class	Width (Ha)	Percentage (%)
Very Close	5	11.011,42	30,97
Close	4	13.764,44	38,72
Moderate	3	9.643,26	27,12
Far	2	998,11	2,81
Very Far	1	134,44	0,38

Source: Hafsari, Kusmartono, Wibisono 2021

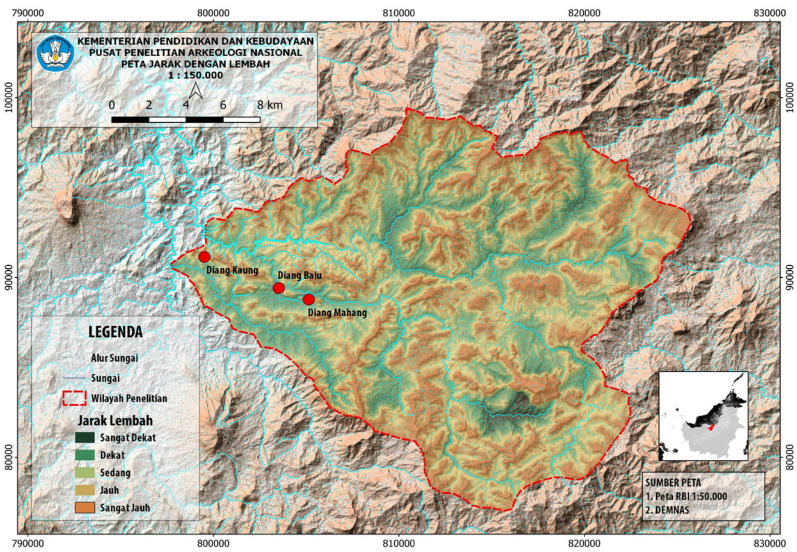

Figure 3. Map of the Class of Valley Elevation
(Source: Hafsari, Kusmartono, Wibisono 2021)

3.2 Map of the Class of Proximity Distance to Water Source

Water is a basic resource that supports life both directly and indirectly. So, water sources are one of the most important factors in choosing settlement locations. Water is a basic need for the living being to survive. The existence of a water source can be a place for animals to gather and become food supplies for humans. Furthermore, water can also it can be a medium for transportation. These possibilities lead to the consideration that the closer to the water source, the more potential a cave is as a place to live.

The variable of the proximity distance to the water source produced a map based on calculations of the distance from the river network in the research area. This variable is classified into five classes with a value of 1-5. The further the distance between the area and the river network, the lower the value. Class determination is based on the range of proximity from the river network in the research area, which is 0-3522m. A class with a value of 5 is given to an area with a distance from a water source between 0-750m, which is the "very close" category. A class with a value of 4 is given to an area with a distance from a water source in the range of 751-1500m, which is a "close" category. While the "moderate" category is given to the distance to the water source between 1501-2250m with a value of 3. The "far" category is given to the area with a distance to the water source between 2251-3000m with a value of 2, and the value of 1 is given to the area with the farthest distance to the water source, which is between 3000-3522m.

Figure 4 shows that the closer an area is to a water source, the color on the map is light blue, while the further away from the water source the color on the map changes to green, yellow, brown, and black respectively. Table 2 shows the area percentage based on the variable distance from the water source. These percentages indicate that the position of the area with a distance from the water source of 0-750m or class with a value of 5 is the largest area consisting of 18,549.64 Ha or 52.18% of the total area of the study, showed by the light blue color in the majority of the area in the map. Then followed by the class with values 4, 3, 2, and 1 respectively, leaving the area with black color (or class value of 1) taking only 1,13% of the study area.

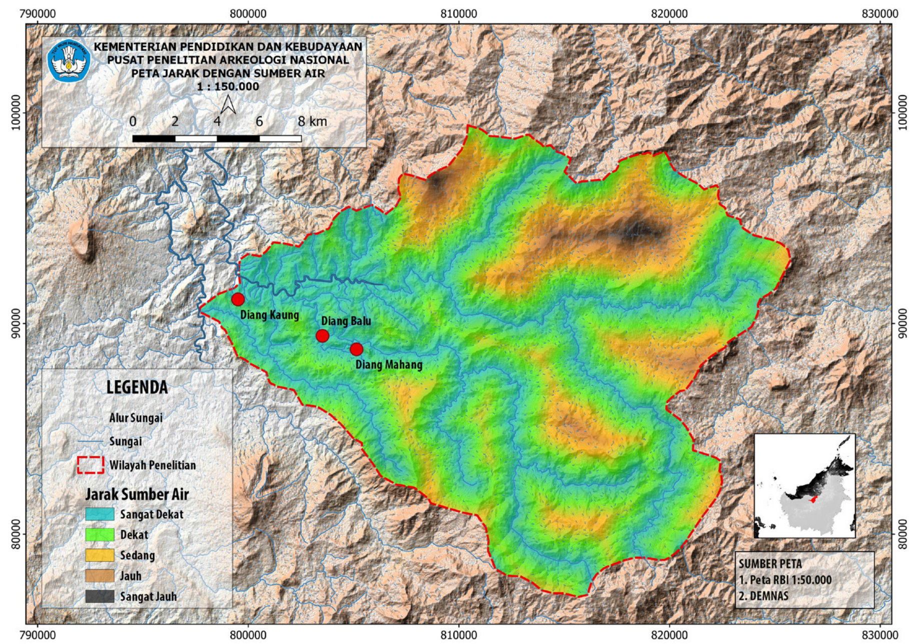

Figure 4. Map of the Class of Proximity to Water Source
(Source: Hafsari, Kusmartono, Wibisono 2021)

Table 2. Area Percentage for Proximity Distance to the Water Source

Distance (meter)	Class	Width (Ha)	Percentage (%)
Very Close	5	18.549,64	52,18
Close	4	10.106,78	28,43
Moderate	3	4.553,45	12,81
Far	2	1.938,29	5,45
Very Far	1	403,35	1,13

Source: Hafsari, Kusmartono, Wibisono 2021

3.3 Map of the Class of Steepness of the Slope

The location and the difficulty of reaching the cave are considered in determining the possibility of the cave as a settlement location. The difficulty in reaching the location of the cave is determined by the variable steepness of the slope. Caves in higher positions tend to be more difficult to reach. Moreover, caves located on a sharply steep slope will be more difficult to reach compared to caves that are on gentle slopes (Muttaqin 2019).

This map was produced by considering the slopes found in the research area. This variable is divided into five classes with a value of 1-5. The steeper the slope, the lower the value. Class determination is based on a range of degrees of the slopes, which is 0-90°. The slope level in this study refers to the distribution of the slope according to Van Zuidam (Zuidam 1985). "Flat" slope with the value of 5 represented the degrees between 0°-4°. Degrees between 5°-8° for "gentle" slopes are given the value of 4. The value of 3 is given to the degrees between 9°-16° for "steep" slopes. Meanwhile, the degrees between 17 ° - 35° show the "very steep" slopes with a value of 2. Furthermore, slopes with above 35° steepness are labeled as "sharply steep" slopes and are given the value of 1. Figure 5 also shows that the "flat" slope is represented by the color light green, while the "gentle", "steep", "very steep", and "sharply steep" slopes are represented by the color yellow, dark green, brown, and light brown respectively.

Table 3 shows the variable percentages based on the slope varieties. The percentages indicate the area with a value of 3 is the largest which is 26,637.49 Ha or 74.93% of the total research area. Meanwhile, the "flat" and "gentle" slopes only take 1.59% and 10,15% of the total area. This is showing that the larger part of the area is in moderate to sharply steep conditions.

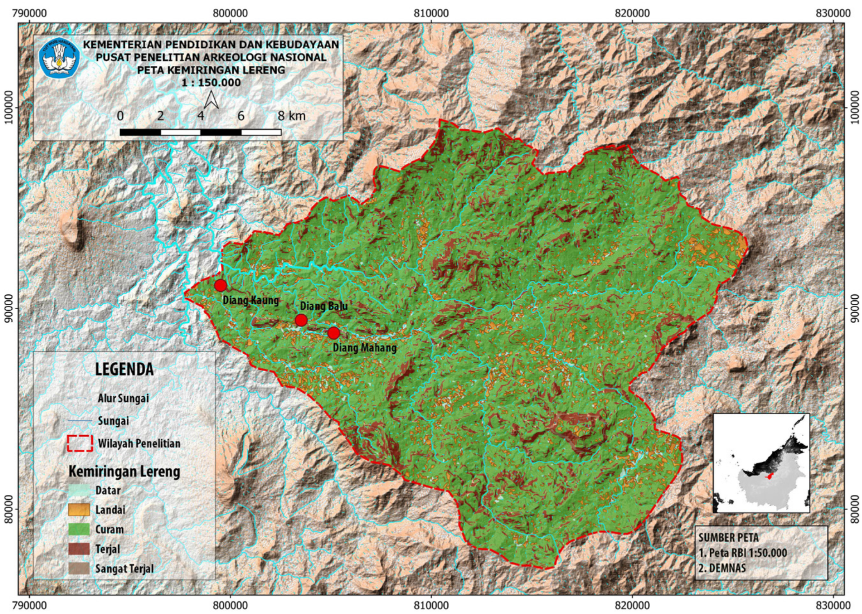

Figure 5. Map of the Class of Steepness of the Slope
(Source: Hafsari, Kusmartono, Wibisono 2021)

Table 3. Area Percentage for Variable Steepness of the Slope

Steepness of the Slope	Class	Width (Ha)	Percentage (%)
Flat	5	566,62	1,59
Gentle	4	3.607,65	10,15
Steep	3	26.637,49	74,93
Very Steep	2	4.623,47	13,01
Sharply Steep	1	115,25	0,32

Source: Hafsari, Kusmartono, Wibisono 2021

3.4 Map of the Class of Accessibility

This map is a combination of the three previous variables, namely the distance from the valley, the proximity distance from the water source, and the steepness of the slopes. The combination of these three variables represents a settlement location probability to be in an area with easy access. The synthesis of these three variables was carried out by giving weighting. The variable proximity to the water source is given a weight of 60%, the difference in valley elevation is given a weight of 30%, and the steepness of the slope is weighted at 10%. The combination and weighting of these three variables produce a map of the class of accessibility shown in Figure 6.

The class of accessibility is divided into five classes with a score of 1-5. The more difficult the area is to access, the lower the score. The "very easy" class with a value of 5 is represented by a yellow color, then the "easy" class with a score of 4 is represented by light green color. Meanwhile, dark green color is given to the "moderate" class with a value of 3. Furthermore, the value of 2 is given to the blue-colored area labeled "difficult" and the smallest value of 1 is given to the area labeled "very difficult", represented by the color purple.

Table 4. Percentage of the Class of Accessibility Area

Level of Accessibility	Class	Width (Ha)	Percentage (%)
Very Easy	5	12.552,09	35,31
Easy	4	17.763,21	49,96
Moderate	3	4.065,37	11,43
Difficult	2	1.055,87	2,97
Very Difficult	1	116,59	0,33

Source: Hafsari, Kusmartono, Wibisono 2021

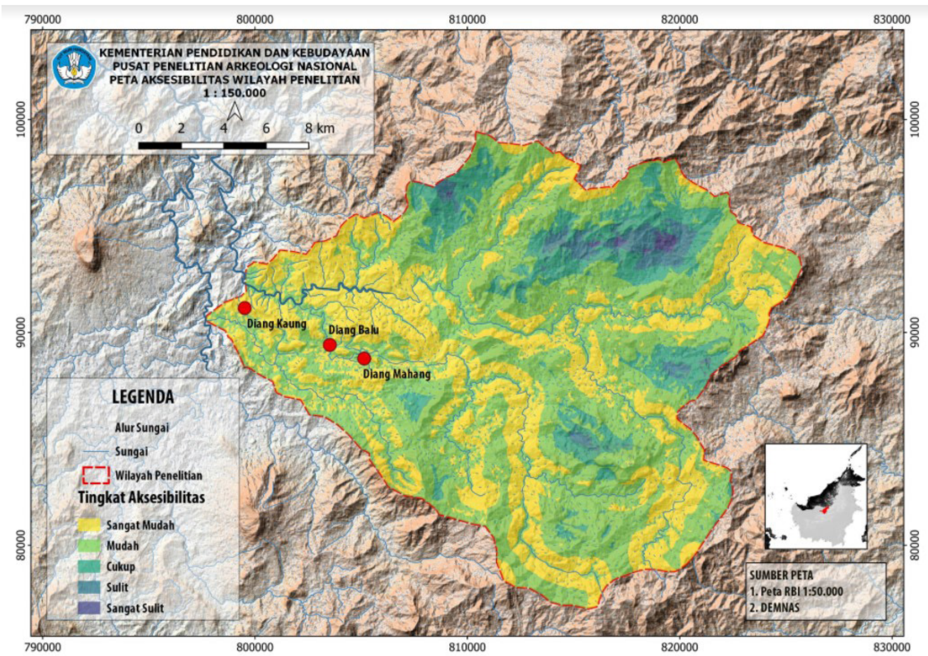

Figure 6. Map of the Class of Accessibility
(Source: Hafsari, Kusmartono, Wibisono 2021)

Table 4 shows the width of the area and the percentages of the level of accessibility divided into 5 classes. The result of this data synthesis indicates that the area labeled "easy" take the largest number with 17,763.21Ha or 49.96% of the total area of the study. Followed by the "very easy" class by 35.31%, making almost 85% part of the research area easily accessible.

3.5 Map of the Direction of the Slopes

The presence of sunlight in the cave has a big influence on the condition of the cave room. Sunlight can create dry conditions and reduce humidity in the cave. The slopes facing east or west are more likely to get more sunlight than the slope facing north or south. In this case, caves opening to the east and west would be favorable as settlement caves, as they received more sunlight to create a dry and less humid cave condition. However, it should also be remembered that the Kapuas Hulu area is a tropical rainforest completely covered by tree canopies. Even though the slopes are facing the direction of the sunlight, the density of vegetation can affect the intensity of light entering the cave.

The direction of the slope variable is classified into three classes. Table 5 shows the percentages of areas based on the slope-facing variable. This result indicates that the position of the area facing northwest is the largest area consisting of 6,445.43 Ha or 18.85% of the total area of the study. However, areas that are considered to have more cave settlements or those oriented towards the east are only shown by 3.13% or 1,069.75Ha. Meanwhile, slopes oriented towards the west cover an area of 3,575.99Ha or 10.46% of the total area of research. Slopes with various facing directions are evenly distributed throughout the study area. So, it cannot be determined which part of the study area has the most potential according to the slope-facing variable. Nevertheless, the direction of the slope remains one of the important variables in determining the potential for prehistoric cave settlements.

Table 5. Percentage of the Direction of the Slope

Direction	Class	Width (Ha)	Percentage (%)
East	3	1.069,75	3,13
West	3	3.575,99	10,46

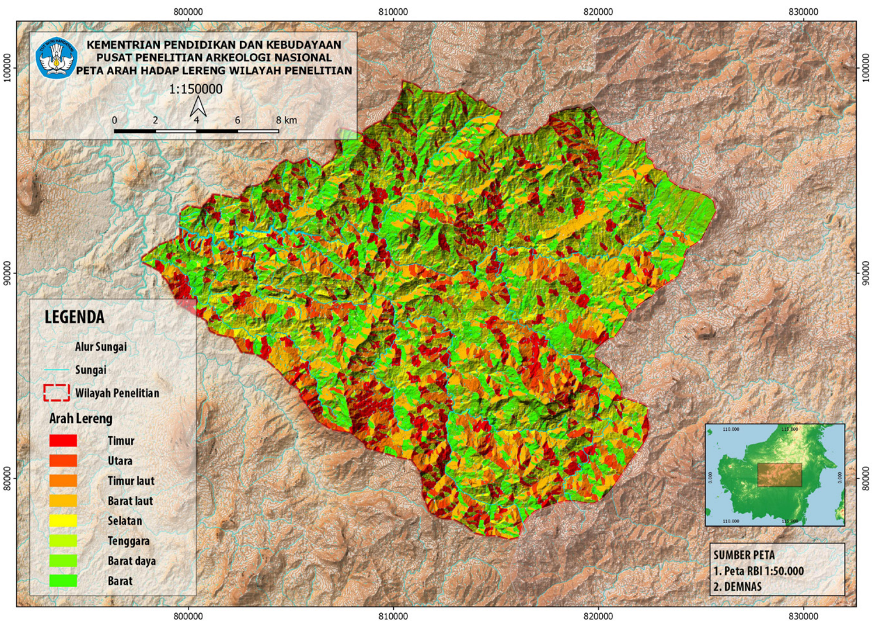

Figure 7. Map of the Direction of the Slopes
(Source: Hafsari, Kusmartono, Wibisono 2021)

Southeast	2	4.807,69	14,06
Southwest	2	4.195,80	12,27
Northwest	2	6.445,43	18,85
Northeast	2	4.051,16	11,85
South	1	5.303,88	15,51
North	1	4.751,32	13,89

Source: Hafsari, Kusmartono, Wibisono 2021

3.6 Map of Lineament Density

Lineament is a forming factor of caves in a karst environment. The density of lineament is a variable that represents that the cave is always on a fault or joint fault. This is seen from the cave genesis factor. Fault and joint movements cut the underground river flow to form horizontal cave mouths.

The lineament density variable produced a map based on the calculation of the lineament. This variable is classified into five classes with a value of 1-5. The sparser the lineament in an area, the lower the value. Figure 8 shows that the color dark blue represents the "very dense" lineaments. Meanwhile, "dense" lineaments represent by the color light blue, followed by the color tosca for the "moderate", and the color light green and yellow for "sparse" and "very sparse" lineaments, respectively. Table 6 shows the percentage of area in 5 classes. These results show that the area with "sparse" lineament is the largest area with 11,715.81Ha or 32.90% of the total study area.

Table 6. Percentage of Lineament Density

Density Level	Class	Width (Ha)	Percentage (%)
Very Dense	5	976,95	2,74
Dense	4	5.883,39	16,52
Moderate	3	10.297,94	28,92
Sparse	2	11.715,81	32,90
Very Sparse	1	6.740,04	18,93

Source: Hafsari, Kusmartono, Wibisono 2021

4. Predictive Model for Potential Cave Settlements

The class of accessibility, the direction of the slopes, and the lineament density were formulated by considering weighting according to the importance of their influence. The variable with the biggest weight is the lineament density which is an indication of the existence of the cave, so it is given a weight of 60%, the class of accessibility variable is given a weight of 30%, and the direction of the slopes is given a weight

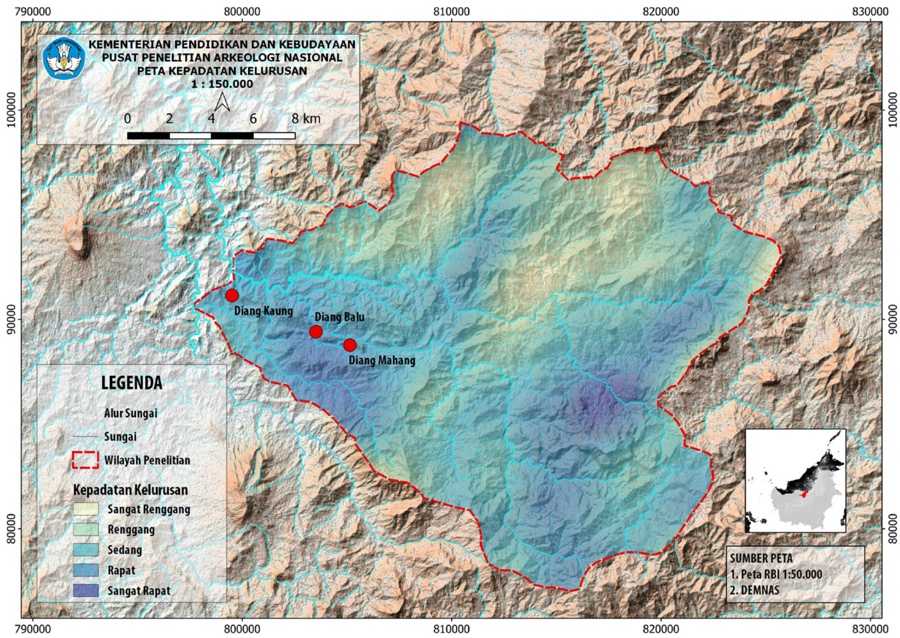

Figure 8. Map of Lineament Density
(Source: Hafsari, Kusmartono, Wibisono 2021)

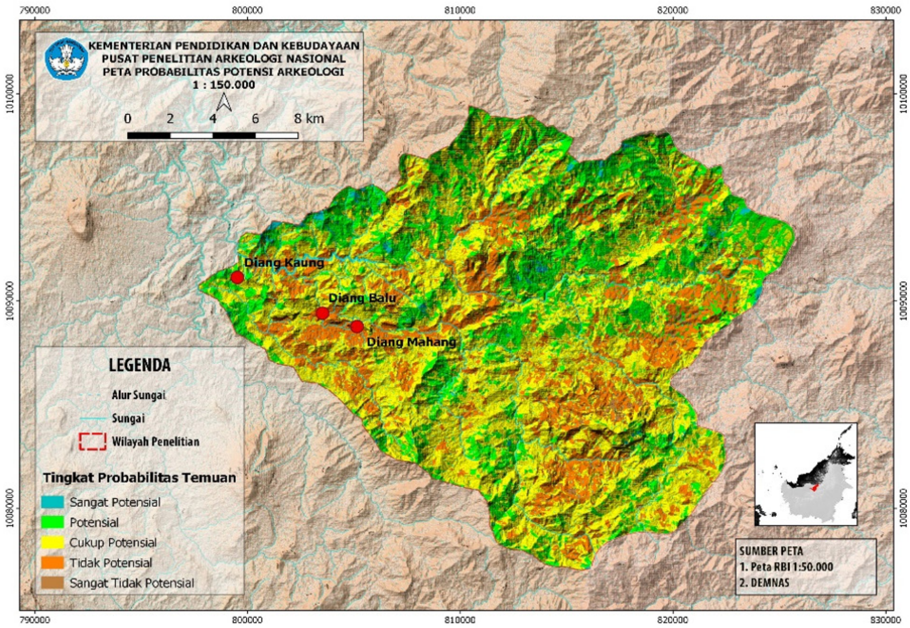

Figure 9. Map of Predictive Model for Potential Cave Settlements Considering Variable Direction of the Slopes
(Source: Hafsari, Kusmartono, Wibisono 2021)

of 10%. The calculation of these variables produced a map in Figure 9 which represents the cave settlement locations in an area with a dense lineament and easy access.

The probability level in Figure 9 is also classified into 5 five categories with a value of 1-5. Figure 9 shows that the light blue color represents the area with the "highly potential" level, followed by the color green with "potential", while the yellow represents "moderately potential", the color orange represents "non-potential", and lastly the "highly non-potential" level showed by the color brown. Table 7 shows the position of the area with a "moderately potential" probability with the largest area of 13,298.70Ha or 37.40% of the total area study.

The variable direction of the slopes applied in the map in Figure 9 indicates the intensity of light entering the caves. Although the weighting of this variable is only 10%, it gives a significant result on the probability of cave settlement. The application of this variable shows that the orange (non-potential) area dominates the southern part of the study area.

Considering the high density of vegetation in the study area, with a full canopy of trees often covering the sun, the variable direction of the slopes may not appraise as an important aspect for humans in the past in choosing caves as settlement locations. Therefore, another probability map was also produced without using the variable direction of the slope, which is shown in Figure 10.

Table 7. Area Percentage for Potential Cave Settlements Considering Variable Direction of the Slope

Probability Level	Class	Width (Ha)	Percentage (%)
Highly Potential	5	474,23	1,33
Potential	4	8459,98	23,80
Moderate	3	13298,70	37,40
Not Potential	2	12276,38	34,53
Highly Not Potential	1	1044,20	2,94

Source: Hafsari, Kusmartono, Wibisono 2021

This map without the variable direction of the slopes shows that the area in the

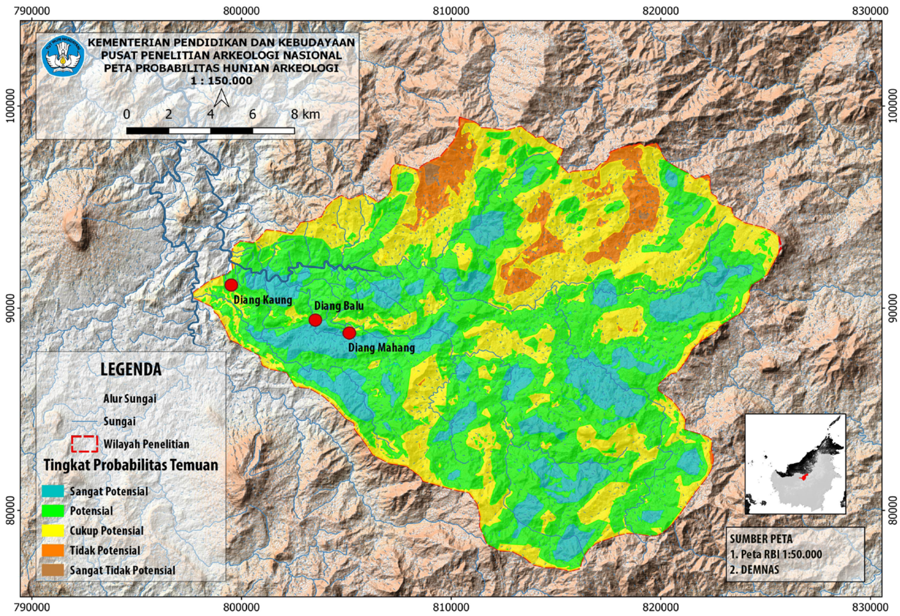

Figure 10. Map of Predictive Model for Potential Cave Settlements Without Variable Direction of the Slopes
(Source: Hafsari, Kusmartono, Wibisono 2021)

southern part is an area with high probability. This is contrasting with the map in Figure 9. This condition shows that this variable has a significant influence on spatial modeling like this, so it is still necessary to pay attention to the actual conditions in the research area.

A significant difference between the effect of the variable direction of the slopes is shown in Table 7 and Table 8. In Table 7 the area with a "moderately potential" level dominated the area by 37.40%, followed by the "non-potential" category by 34,53%. Meanwhile, the "very potential" category is only 1.33% of the total research area. Whereas Table 8 shows that the "potential" category is the largest area with 45.50%, followed by the

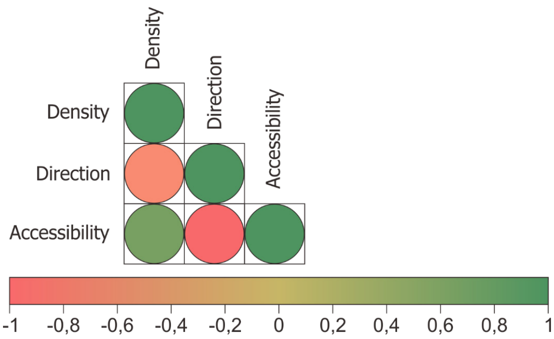

Figure 11. Correlation between three variables
(Source: Hafsari, Kusmartono, Wibisono 2021)

"moderately potential" with 32.02%, and the "very potential" category with the color blue is 16.21%. These percentages confirmed that without considering the variable direction of the slopes, the great majority by 93.73% of the study area has the potential to contain caves for settlements.

Table 8. Area Percentage for Potential Cave Settlements Without Variable Direction of the Slope

Probability Level	Class	Width (Ha)	Percentage (%)
Probability Level	5	5762,27	16,21
Highly Potential	4	16172,14	45,50
Potential	3	11.381	32,02
Moderate	2	2.106,61	5,93
Not Potential	1	117,75	0,33

Source: Hafsari, Kusmartono, Wibisono 2021

Figure 11 shows the results of the correlation analysis of the three variables. We found a high correlation between lineament density and accessibility variables. Based on this, we considered only using these two variables as the selected variable in the predictive model of cave settlements in the karst area of the Kapuas Basin. Meanwhile, we eliminated the variable direction of the slopes because it did not show a significant correlation in this analysis.

5. The Excavated Caves positioning in the Predictive Model

Based on the location of the three caves that have been excavated (Diang Kaung, Diang Balu, and Diang Mahang) on the map in Figure 9, it can be seen that Diang Kaung is located in an area with potential probability, while the other two caves are located in the non-potential area. However, the excavation in Diang Balu and Diang Mahang showed that these two caves contained highly potential archaeological evidence. This may indicate that the past humans who inhabited this area chose a settlement location not only based on ideal environmental conditions but also had other considerations. These considerations may be factors of safety, comfort, and other socio-cultural preferences, which still require further investigation.

On the other hand, if we take a look at Figure 10 which is a probability map without considering the direction of the slopes, these three caves are in the "potential" area right at the edge of the "high potential" area. This may confirm that the direction of the slopes is not an important factor in determining the cave settlements in the rainforest area of the Kapuas Basin.

6. Conclusion

The pattern of human settlements that inhabited the Kapuas Basin area in the past could be mapped better if the research is carried out more intensively. This predictive model is expected to be a guide in the implementation of further research and exploration in this area. Following this predictive model, research and exploration in the coming years will focus on areas of "high potential" and "potential", indicated by blue and green, which are in areas close to the three caves that have been excavated. The expected result is that future research and exploration will become more focused and directed to answer the big research questions in the area of Kapuas Basin, regarding human interaction with the environment in the Late Pleistocene-Early Holocene period during extreme climate change as well as adaptation strategies and technological innovations for hunter-gatherers to settle in the area. The increasing effectiveness of the research is also expected to affect in increasing the efficiency of research capital, including human resources, as well as the efficiency of budget and research time.

References

Anggraeni, H.M. Nies Ambary, D.D. Bintarti, and E. Soekatno (1992) "Laporan kegiatan penelitian arkeologi selama PELITA III."

Burton-Johnson, Alexander (2013) *Origin, emplacement and tectonic relevance of the Mt. Kinabalu granitic pluton of Sabah, Borneo.* Durham University.

Butzer, K.W. (1982) *Archaeology as Human Ecology: Method and theory for a contextual approach.* Cambridge University Press.

Fage, L.H., and J.M. Chazine (2010) "Borneo, Memory of the Caves." In *Le Kalimanthrope*.

Hafsari, N.L.G.D Mega, Vida P.R. Kusmartono, M.W. Wibisono, and A.G. Purnawibawa (2020) *Predictive Model Kawasan Okupasi Awal Holocene di DAS Hovorit Kawasan Cekungan Kapuas (Pegunungan*

Muller), Kabupaten Kapuas Hulu, Kalimantan Barat. Jakarta: Pusat Penelitian Arkeologi Nasional.

Hindarto, I., Vida P.R. Kusmartono, and E. Herwanto (2018) "Potensi arkeologi di daerah aliran sungai Hovongan, Kabupaten Kapuas Hulu, Kalimantan Barat." In *Berita Peneritian Arkeologi 12*. Banjarmasin: Balai Arkeologi Kalimantan Selatan.

Kusmartono, Vida P.R, I. Hindarto, E. Herwanto, U. Oktrivia, N.L.G.D. Mega Hafsari, and M.W. Wibisono (2019) *Okupasi Pemburu-Peramu Dan Strategi Survival Di Kawasan Cekungan Kapuas (Pegunungan Müller) Pada Pleistosen Akhir-Awal Holosen Di Kabupaten Kapuas Hulu, Kalimantan Barat Tahap I.* Banjarmasin: Balai Arkeologi Kalimantan Selatan.

Kusmartono, Vida P.R., I. Hindarto, and E. Herwanto (2017) "Late Pleistocene to recent: Human activities in the deep interior equatorial rainforest of Kalimantan, Indonesian Borneo." *Elsevier Quartenary International* 448: 82-94.

Kusmartono, Vida P.R., Sunarningsih, B. Sugiyanto, and N.N. Susanto (2008) "Penelitian pemukiman neolitik Nanga Balang, Kabupaten Kapuas Hulu, Kalimantan Barat."

Mink, Philip B., David Pollack, and B. Jo Stokes (2006) "Points vs. Polygons: A Test Case Using a Statewide Geographic Information System." Chap. 10 in *GIS and Archaeological Site Location Modeling*, edited by Mark W. Mehrer and Konnie L. Wescott. New York: CRC Press.

Muttaqin, L.A. (2019) *Pemodelan Maxent (Maximum Entropy) Berbasis Citra Penginderaan Jauh Untuk Pendugaan Situs Gua Hunian Prasejarah Di KawasanKarst Gunungsewu, Kabupaten Gunung Kidul, Prov. D.I. Yogyakarta.* Yogyakarta: Universitas Gadjah Mada.

Plutniak, S., A.A. Oktaviana, B. Sugiyanto, J.M. Chazine, and F.X. Ricaut (2014) "New ceramic data from East Kalimantan: The cord-marked and red-slipped sherds of Liang Abu's layer 2 and Kalimantan's pottery chronology." *Journal of Pacific Archaeology* 5 (1): 90-99.

Simanjuntak, Truman (2002) "Neolihic features in Indonesia." In *Gunung sewu in prehistoric times*, 205-209. Yogyakarta: Gajadmada University Press.

Yaworsky, Peter M., Kenneth B. Vernon, Jerry D. Spangler, Simon C. Brewer, and Brian F. Codding (2020) "Advancing Predictive Modeling in Archaeology: An evaluation of regression and machine learning methods on the Grand Staircase-Escalante National Monument." *PLos ONE* 15 (10). doi:https://doi.org/10.1371/journal.pone.0239424.

Zuidam, R.A. van. (1985) *Aerial Photo-Interpretation in Terrain Analysis and Geomorphologic Mapping.* The Hague: Smits Publ.