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Predictive Modeling of Pre-Columbian Sites in Jamaica Using Multi-Criteria Analysis

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The impact of climate change threatens numerous cultural heritage sites around the world, particularly those that are found along the coast. Middens and infrastructure of Indigenous populations, both identified and undiscovered are at risk of being lost. There is a need to conduct rapid assessments for analysis and interpretation to safeguard the wealth of information contained along the coast and to learn more about these ancestral people. Jamaica along with almost all other small island developing states will be significantly impacted by sea-level rise within the next 50-100 years. This will result in the loss of up to and possibly exceeding 1 km of coast, (due to topography) as sea-level is expected to rise by between 0.3-1 m. It therefore becomes necessary to use specific criteria of Pre-Columbian life and habit to determine possible locations of sites for exploration and excavation. Multicriteria analysis through Geographic Information Systems/Science presents us with an opportunity to use some basic machine learning to predict site location. This would provide a framework for prioritizing, planning and funding various excavations before these sites are lost forever.

L'impact du changement climatique est une menace pour des nombreux sites du patrimoine culturel autour du monde, notamment ceux que l'on trouve le long de cote. Les anciens tas de déchets et l'infrastructure indigène, à la fois connu et inconnu risquent d'être perdus. Il y a un besoin de mener des évaluations rapides via des analyses et interprétations pour sauvegarder la richesse d'information contenue sur le littoral ainsi que savoir plus sur ces peuples ancestraux. Jamaïque avec presque toutes les autres petites îles seront considérablement affectées par le monté du niveau de la mer monte dans les 50 - 100 prochaine années. Cela résultera dans la perte de jusqu'à, et dépassant peut-être, 1km de la cote, (à cause de la topographie) comme la mer devrait s'élever entre 0,3 à 1m. Par conséquent, il devient nécessaire d'utiliser des critères spécifiques de la vie et des pratiques "Précolombiennes", et l'habitude à déterminer les emplacements possibles des sites pour l'exploration et les fouilles. Analyse multicritère par les Systèmes/Sciences d'information géographique nous assurent une opportunité d'utiliser quelques d'apprentissages automatiques pour prédire les emplacements des sites. Cela fournirait un système pour hiérarchiser, la planification et financement de diverses fouilles avant de perdre ces sites.

El impacto del cambio climático amenaza numerosos sitios del patrimonio cultural en todo el mundo, en particular los que se encuentran a lo largo de la costa. Los basureros y la infraestructura de las poblaciones indígenas, tanto identificados como no descubiertos, corren el riesgo de perderse. Existe la necesidad de realizar diagnósticos rápidos de análisis e interpretación para salvaguardar la riqueza de información contenida a lo largo de la costa y conocer más sobre estos pueblos ancestrales. Jamaica, junto con casi todos los demás pequeños estados insulares en *desarrollo, se verá significativamente afectada por el aumento del nivel del mar en los próximos 50 a 100 años. Esto resultará en la pérdida de hasta y posiblemente más de 1 km de costa (debido a la topografía) ya que se espera que el nivel del mar aumente entre 0,3 y 1 m. Por lo tanto, se hace necesario utilizar criterios específicos de vida y hábitos precolombinos para determinar las posibles ubicaciones de los sitios de exploración y excavación. El análisis multicriterio a través de los Sistemas de Información Geográfica/Ciencia nos presenta la oportunidad de utilizar algo de aprendizaje automático básico para predecir la ubicación del sitio. Esto proporcionaría un marco para priorizar, planificar y financiar varias excavaciones antes de que estos sitios se pierdan para siempre.*

Introduction

The island of Jamaica is located in the north central Caribbean in the Greater Antilles (**Figure 1**). The history of Jamaica has been categorized by the earliest inhabitants, the Pre-Columbian people(s) who inhabited the island prior to the Spanish arrival led by Christopher Columbus in 1494 (Bryan 1992). With Spanish occupation came the first introduction of Enslaved Africans, some of these individuals and their descendants later freed themselves and formed enclaves in the mountainous interior, and later adopted the name Maroons -from the French term marronage, which means to run away (Gaspar 1979). The Spanish battled the English for Jamaica, but eventually ceded to the English through the Treaty of Madrid in 1670 (Bryan 1992). With the English conquest came the trade and influx of Enslaved Africans. With the British occupation came others, namely, Welsh, Scottish, Germans, among others. Post emancipation (1838) saw the arrival indentured laborers from the India and China who arrived between 1845 and 1917. As a result of these multicultural interactions the Jamaican population now enjoys a rich heritage and legacy.

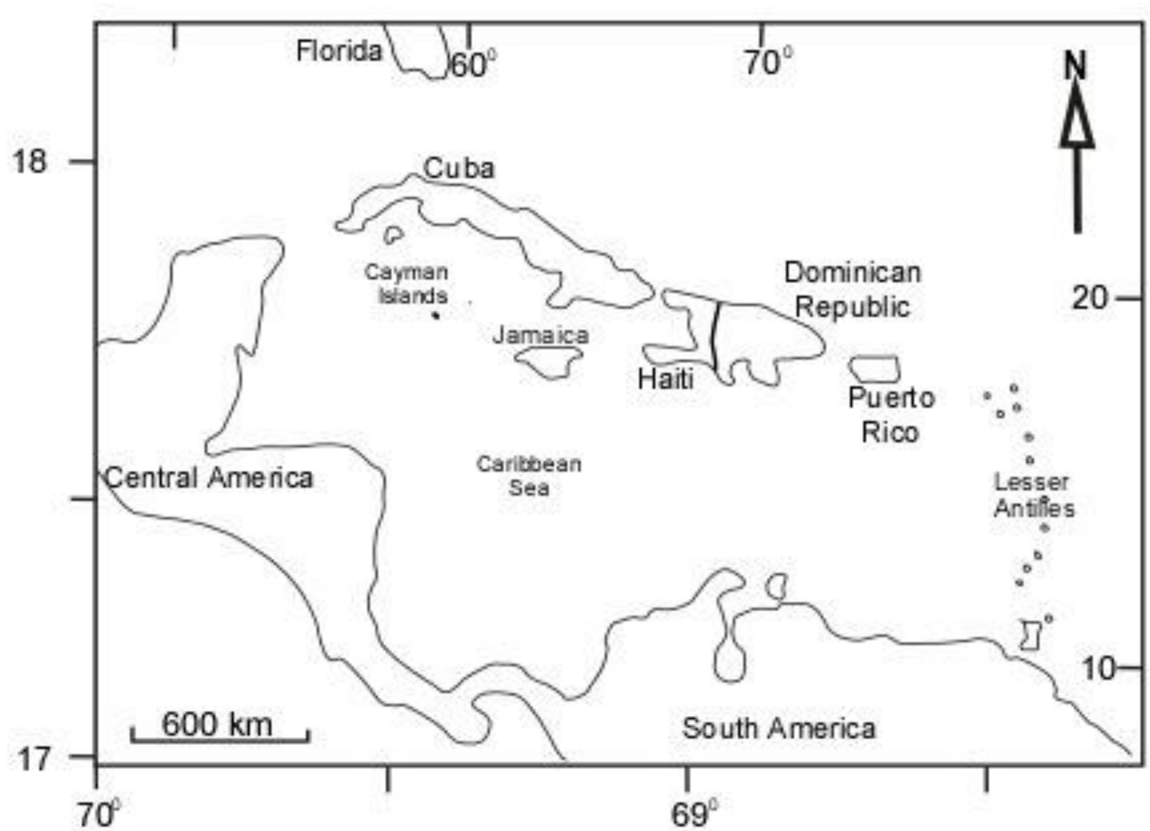

Figure 1. Sketch map of the Caribbean showing the Greater Antilles. Modified after James-Williamson et al. 2016.

The subject of this article is primarily the habitation of the island by Indigenous people prior to the arrival of Columbus. Much work has been documented through artifact recovery and excavation, however, there has not yet been a study that predicts or suggests neither new sites nor sites under threat. With the effects of climate change, it is of particular importance that these sites are identified, excavated and the collections preserved for future generations (Howard et al. 2016; Ezcurra and Rivera-Collazo 2018). Housing and industrial development presents a unique threat to such sites, especially those not yet unearthed. A study such as this will provide the basis for protection and preservation from development or hazardous activity. The scientific and educational value of such sites are immeasurable and can be incorporated within the development process within satisfactory parameters (Balla et al. 2014; Danese et at. 2014; Nicu et al. 2019).

Pre-Columbian Jamaica

The Caribbean region is believed to have been settled between 5,000 and 8,000 years ago by Indigenous populations from Central and South America (Fitzpatrick 2015). The island of Jamaica is believed to have been uninhabited until the 7th century when it was colonized by the Ostionan Ostionoids (Rouse 1992). The Ostionans are referred locally as the Little River Complex or Redware due to their bright red pottery. William Keegan's article in this volume highlights that the term "Redware" is quite a misnomer. The Jamaican Ostionan culture has been traditionally viewed as a coastal culture found largely in the parishes of St. Elizabeth and Manchester with a few sites in Westmoreland and St. Ann. Their sites are located in proximity to the sea or a riverine resource. The Jamaican Ostionan is believed to have been dependent on marine resources.

According to the Rousean model by AD 900 another migration wave brought the Meillacan Ostionoid or the White Marl Complex to the island (Rouse 1992). The Meillacans had a number of sites along the coast; however, the majority of their sites were further inland and within reach of a water source (Atkinson 2019). The Meillacan sites are widely distributed across the island and have been observed on the surrounding isles and cays. Their subsistence is a mixture of marine, riverine and terrestrial resources, which seems to be dependent on available resources and preference.

During the 11th century a localized culture known as the Fairfield Complex or Montego Bay Style evolved in Jamaica. The Montego Bay Style is viewed as a variant of the Meillacan Ostionoid. It has been observed particularly in western Jamaica in the parishes of St. James, Hanover, Westmoreland, Trelawny and St. Ann. The subsistence practices of the Montego Bay Style peoples are largely dependent on marine resources.

Generally, in Jamaica, the term "Taíno" is used as an umbrella heading for the Pre-Columbian sites and cultures found on the island. This however is not accurate as the Ostionan and Meillacan Ostionoids and their respective variants are viewed as predecessors to the Taíno. The culture referred to as the Taíno is believed to have developed in the Caribbean region ca. AD 1200 (Wilson 1997) and existed into the contact period. This culture was widely distributed across the island. Ethnohistoric accounts highlight that Jamaica had a sizeable Indigenous population. Taíno villages recorded include Maima (St. Ann), Ameyro (St. Thomas), Caguay (Port Royal, Kingston) and the Guatguata region (St. Mary).

Based on Atkinson's (2019) research almost 600 pre-Columbian sites have been discovered across the island. Approximately a third of these sites are located on the coast (Atkinson 2019). It is believed that this number of sites is not exhaustive. The exploration and inventory of sites across the parishes have not been consistent since efforts of The Archaeological Society of Jamaica during the 1960s and 1980s.

Geographic Information Systems

Geographic Information Systems (GIS) have been used for problem solving in environmental (Natesan and Parthasarathy 2010; Putri et al. 2014; Arnous et al. 2015), social (Hawthorne and Kwan 2012; Feng et al. 2016; Mpofu et al. 2018) and geoscientific studies (Dai and Lee 2002; Metternicht et al. 2005; Bétard and Peulvast 2019). Since the 1980s there has been rapid growth of specialized software for spatial analysis, remote sensing and three-dimensional analyses (Nijkamp and Rietveld 1984; Haining 1989; Goodchild et al. 2000; Anselin et al. 2005). In recent times there has been much use in archaeological studies to determine activities and their relationship with the physical environment of past populations (De Leat et al. 2007). Spatial analysis, an additional analytical function of GIS, has been used as a tool to analyze terrain to determine how site characteristics are utilized by past civilizations and how cultural practices, social structure and anthropological thought are incorporated with specific features of the landscape – geology and geomorphology (Trouillot 1992; Anselin and Getis 1992) for archaeological reconstruction (Kennedy 1989; Robertson 1999).

These techniques are not new to the Caribbean landscape; an entire volume has been dedicated to Archaeology and Geoinformatics in the Caribbean (Reid 2008). Multi-criteria analysis and by extension Analytical Hierarchical Process (AHP) modeling have been used for numerous assessments related to site suitability (Vasiljević et al. 2012; Chang et al. 2008; Mahini and Gholamalifard 2006), predictive modeling (Otuoze et al. 2021; Vujičić et al. 2018; Verhagen and Whitely 2012), vulnerability (Loumi and Redjem 2021; El-Zein and Tonmoy 2015; Kim and Chung 2013) among others.

Predictive modeling is a useful tool in determining locations where possible archaeological sites may have existed on the landscape, for site preservation and conservation as well as protection from destruction from land use development (Wachtel et al. 2018). This paper seeks to provide using available data a model to determine where additional Pre-Columbian sites may exist in Jamaica. This paper seeks to utilize a geospatial approach for determining the location of Pre-Columbian sites in Jamaica. This study is relevant on several counts - it can aid in site prioritization and removing the “guess work” and accidental finds from site exploration and excavation process; to devise site pre-excavation plan and geomorphosite analyses. This work suggests a more systematic approach to exploration and by extension documentation, management, and conservation. This assessment will aid in determining sites that are at risk as well as sites that could be under threat for development, natural hazards, and climate change, to name a few.

Materials & Methods

In order to investigate or apply a spatial analysis for the identification of Pre-Columbian sites across the island of Jamaica, one must first seek to examine the structure and the characteristic of the Pre-Columbian village and try to identify where specific functional units exist. In multi-criteria analysis these functional units are the design criteria for model creation. These criteria include physical characteristics of the landscape such as location of rivers, protected coastlines and bays and arable hills along with characteristics of the Pre-Columbian village and way of life. The criteria being utilized in this study are generated from both published and unpublished works which have described particular aspects of Pre-Columbian life. The site profile has been taken from Atkinson (2006), Allsworth-Jones (2008), Lyew-Ayee and Conolley (2008), Conolley (2011), Burley et al. (2017), and Atkinson (2019).

The spatial data used for the models were derived from the PhD dissertation database from Atkinson (2019). The database includes information on 577 sites found in Jamaica and its offshore isles. The research encompassed natural and cultural characteristics. The natural characteristics included topography, elevation, proximity to water resources, geology/lithology, soil type, soil texture and associated natural vegetation. Cultural characteristics incorporated site type, site period, and function classifications in addition to a record of the cultural material recovered.

Design Criteria

Although previous researchers, such as Lyew-Ayee and Conolley (2008) have indicated site characteristics for Pre-Columbian communities, a more systematic approach using the data derived through archaeological excavations was more appropriate. That way, biases would not be introduced into the analyses. Having combed through the literature and interrogated the PhD database provided in Atkinson’s dissertation (2019), several considerations were considered for predicting locations of Pre-Columbian settlements. Spatial data was extracted for caves and sites of excavations and artifact recovery. This allowed for the selection of five criteria – geology, distance from rivers, distance from the coast, elevation, caves, and distance from wetlands (mangrove areas). These criteria were selected based on preliminary plots of existing Pre-Columbian sites (Atkinson 2019; Allsworth-Jones 2008; Atkinson 2006). **Table 1** expands on the criteria and how they have been used.

Table 1. Design criteria for the predictive model of Pre-Columbian Sites in Jamaica.

Criteria	Dataset	Buffer	Resolution	Data Source
Geology	Simplified Geological Map of Jamaica		1:600,000	www.sfmgeology.com NSDMD
	Pre-Columbian Sites with Caves and Burial Sites		1:600,000	Atkinson (2019)
Distance from Rivers	Hydrology – Rivers Shape file	0 m - 10 km	1:600,000	Water Resources Authority
Distance from the coast	Coastline	0 m - 5 km	1:600,000	NSDMD
Elevation	DEM		1:600,000	ESRI Open Data
Distance from Wetlands	Wetlands and Mangrove Swamps	0 m - 5 km	1:600,000	Forestry Department, Jamaica
Caves	Caves of Jamaica	0 m - 5 km	n/a	Jamaica Caving Organization

The pre-existing Pre-Columbian dataset was used to separate each criterion into different classes. This separation is based on initial spatial analysis and as such is specific to Jamaica. This was done to determine the most to the least suitable conditions for settlement. To achieve this, the number of recorded Pre-Columbian locations within each respective class was quantified. The largest to smallest subdivisions were identified, given a ranking and a corresponding rating ranging from one to six was assigned, with one being the best and six being the worst. A rating was given to fulfil the requirements of a weighted suitability analysis. These are illustrated in **Tables 2-7**. This data served as input for ArcGIS, where maps of the criteria, their respective subdivisions and assigned rankings were generated atop a 1:600,000 map of Jamaica. The methodology for the preparation of the predictive model is derived from the current state of the art as used and described by various practitioners (e.g., Siart et al. 2008; Balla et al. 2014; Vujičić et al. 2018). This methodology involves the combination of the shape files for each criterion using equal weights to generate the predictive model. The predictive model is then subjected to sensitivity analysis which involves the individual removal of each criterion from the model to determine how each criterion impacts the model. This produces scores that are then used according to Saaty (1980) for the Analytical Hierarchical Process (AHP). The results of the AHP then provide the final predictive model which then suggests where possible sites are located. The model is then tested to determine if pre-existing sites have been identified by the model along with new sites. An attempt can then be made in future studies to indicate the sites that are at risk to flooding, tsunami, storm surge and sea-level rise. Updated land use maps would be required to determine the threats associated with development. The data available for this is over 20 years old and would not give an accurate picture so this analysis will be included in future work.

Results

The criteria subdivision ratings were all combined to produce a general predictive model. For the purpose of this map, all the criteria were given equal weights in an attempt to later determine the model's sensitivity to each criterion. The formula below was used to produce scores for locations across the island. Equation 1 was used to produce scores for locations across the island.

(1) *Scores = [0.1666 x Geology Rating] + [0.1666 x Dist. from Rivers Rating] + [0.1666 x Dist. from Coast] + [0.1666 x Elevation] + [0.1666 x Dist. from Wetlands Rating] + [0.1666 x Dist. from Caves]*

Table 2. Geology criteria and ranking.

Geological Group	No. of Sites	% of Sites	Ranking	Rating
White Limestone (shallow)	216	50.23%	1st	1
White Limestone (deep)	66	15.35%	3rd	3
Alluvium	68	15.81%	2nd	2
Coastal Group	41	9.53%	4th	4
Cretaceous (+metamorphic)	20	4.65%	5th	5
Wagwater and John Crow Rift Deposits	12	2.80%	6th	6
Yellow Limestone	7	1.63%	7th	6

Table 3. Distance from Rivers criteria and ranking.

Distance from Rivers (m)	No. of Sites	% of Sites	Ranking	Rating
0-100	51	11.97%	3rd	2
101-200	26	6.10%	9th	5
201-500	87	20.42%	1st	1
501-1000	77	18.08%	2nd	1
1001-1500	43	10.09%	5th	3
1501-2000	28	6.57%	8th	5
2001-3000	30	7.04%	6th	4
3001-5000	48	11.27%	4th	3
5001-10000	30	7.04%	6th	4
>10000	6	1.41%	10th	6

Table 4. Distance from the coast criteria and ranking.

Coastal Buffers (m)	No. of Sites	% of Sites	Ranking	Rating
0-100	23	5.31%	6th	6
100.1-500	60	13.86%	4th	4
500.1-1000	49	11.32%	5th	5
1000.1-2000	66	15.24%	3rd	3
2000.1-5000	76	17.55%	2nd	2
>5000	159	36.72%	1st	1

Table 5. Elevation criteria and ranking.

Elevation Class (m)	No. of Sites	% of Sites	Ranking	Rating
0-100	225	51.96%	1st	1
100.1-200	55	12.70%	3rd	3
200.1-300	45	10.39%	4th	4
300.1-500	65	15.01%	2nd	2
500.1-750	37	8.55%	5th	5
750.1-1000	6	1.39%	6th	6
1000.1-1200	0	0.00%	-	6
1200.1-1500	0	0.00%	-	6
1500.1-2000	0	0.00%	-	6
2000.1-2500	0	0.00%	-	6

Table 6. Distance from wetlands criteria and ranking.

Distance from Wetlands (m)	No. of Sites	% of Sites	Ranking	Rating
0-1000	71	11.97%	1st	1
1000.1-2000	37	6.10%	2nd	2
2000.1-3000	27	20.42%	3rd	3
3000.1-4000	27	18.08%	3rd	3
4000.1-5000	27	10.09%	3rd	3

Table 7. Distance from Caves criteria and ranking.

Distance from Caves (m)	No. of Sites	% of Sites	Ranking	Rating
0-100	4	0.92%	8th	6
101-200	11	2.54%	7th	6
201-500	89	20.55%	2nd	2
501-1000	54	12.47%	5th	5
1001-2000	96	22.17%	1st	1
2001-3000	80	18.48%	3rd	3
3001-5000	64	14.78%	4th	4
>5000	35	8.08%	6th	5

The criteria were ranked and processed using ArcGIS. A simplified geological map of Jamaica (modified after Brown and Mitchell 2010) was used for the geology. This was broken down into major lithological groups rather than at the formation level (**Figure 2**). Observations made at sites during excavation and artifact recovery documented the type of lithology and soil associated with each site (Atkinson 2019). Geology was considered an important criterion as it determines the soil type in an area, stone tools are derived from specific rock formations, caves are found in limestone, and caves have been indicated to date as sites for burial and rock art such as pictographs and petroglyphs (Atkinson 2019).

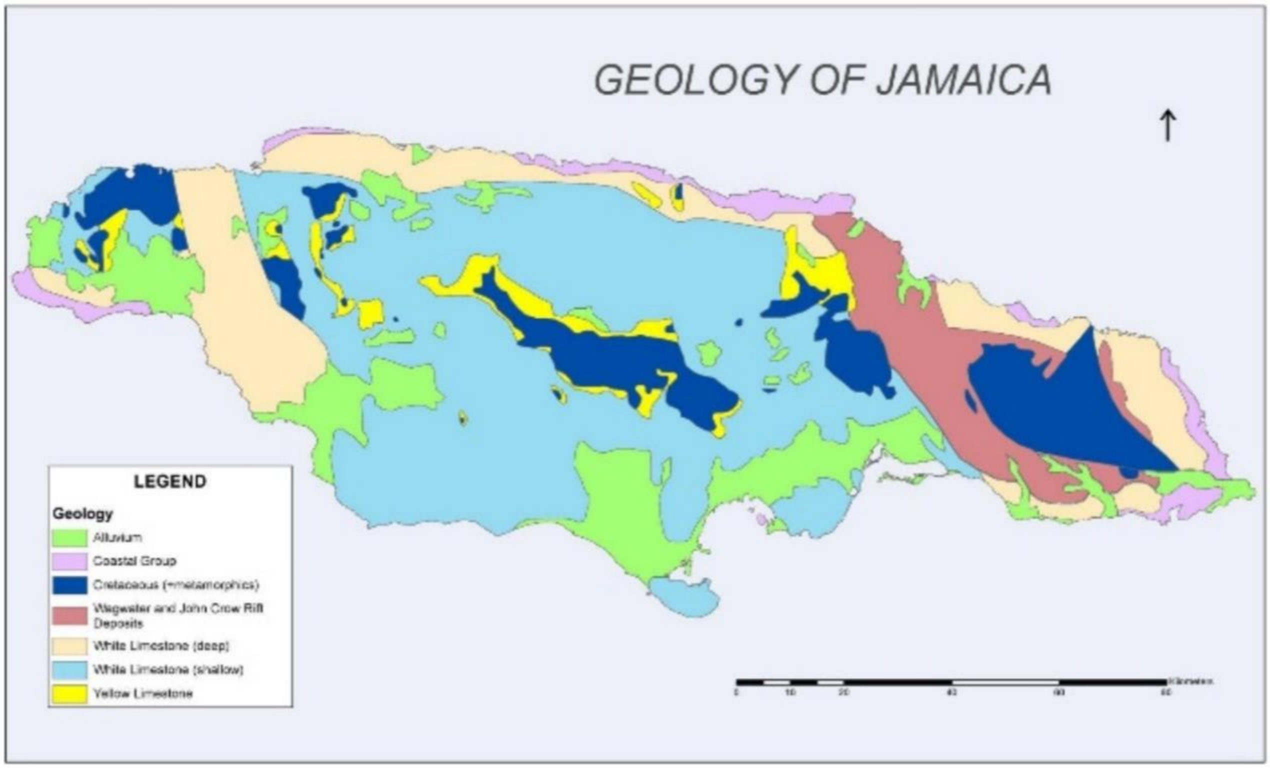

Figure 2. Simplified geological map of Jamaica. (Source: Brown and Mitchell 2010).

The river shape file shown in **Figure 3** shows the buffers generated from site observations. Sites have been located from within 100 m to 10 km from a river (Conolley 2011; Atkinson 2019). As such the ranked data for each buffer was included on the map.

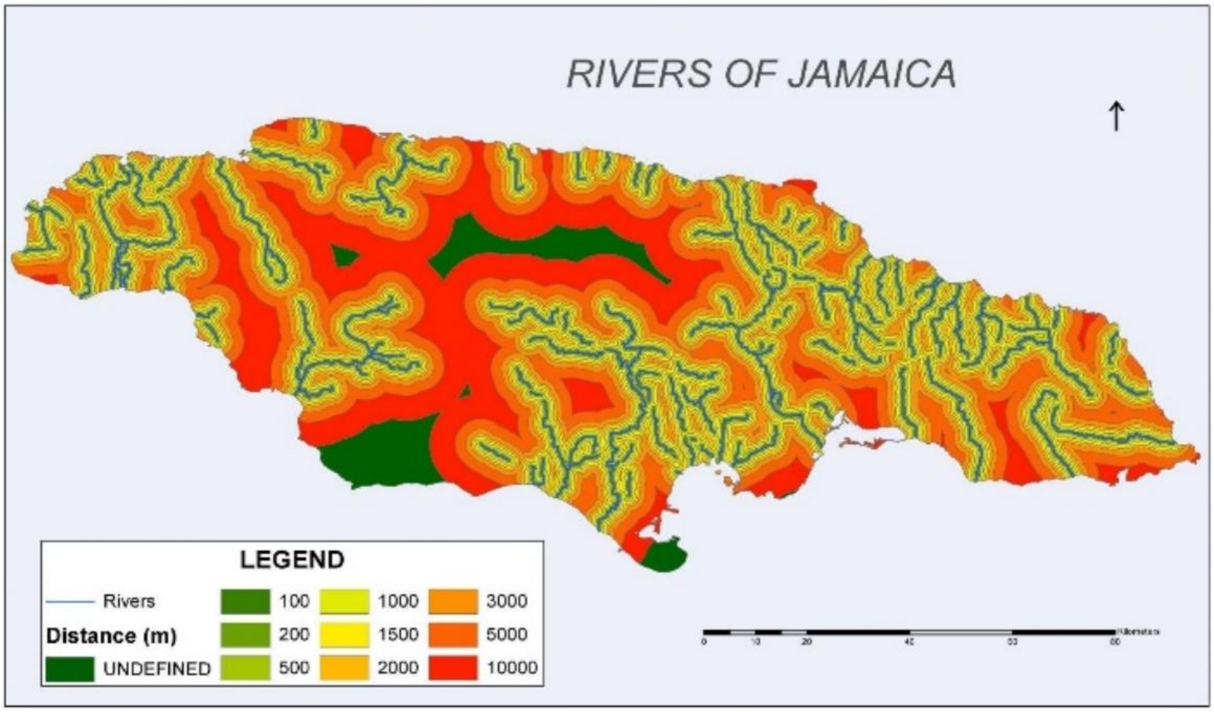

Figure 3. Map showing major rivers in Jamaica. The Buffers used in the model have been included. (Source: Water Resources Authority).

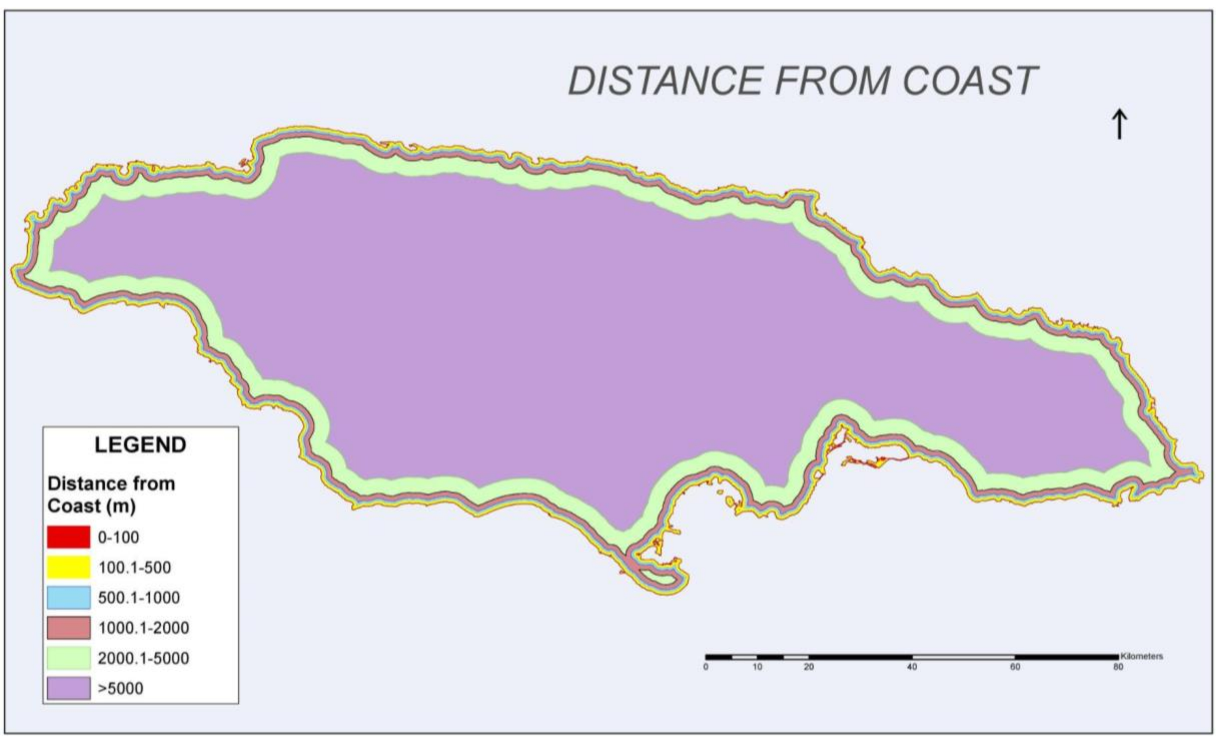

Figure 4. Map showing the Jamaican coastline. The Buffers used in the model have been included. (Source: NSDMD).

Pre-Columbian sites have been identified as far as 5 km from the coast, with some sites even further inland (Conolley 2011). The buffers created here shows site distances from the coast that range from 100 m to above 5 km (**Figure 5**). These buffers are derived from site observations recorded in field notes and other published sources (e.g., Allsworth-Jones 2008; Atkinson 2019).

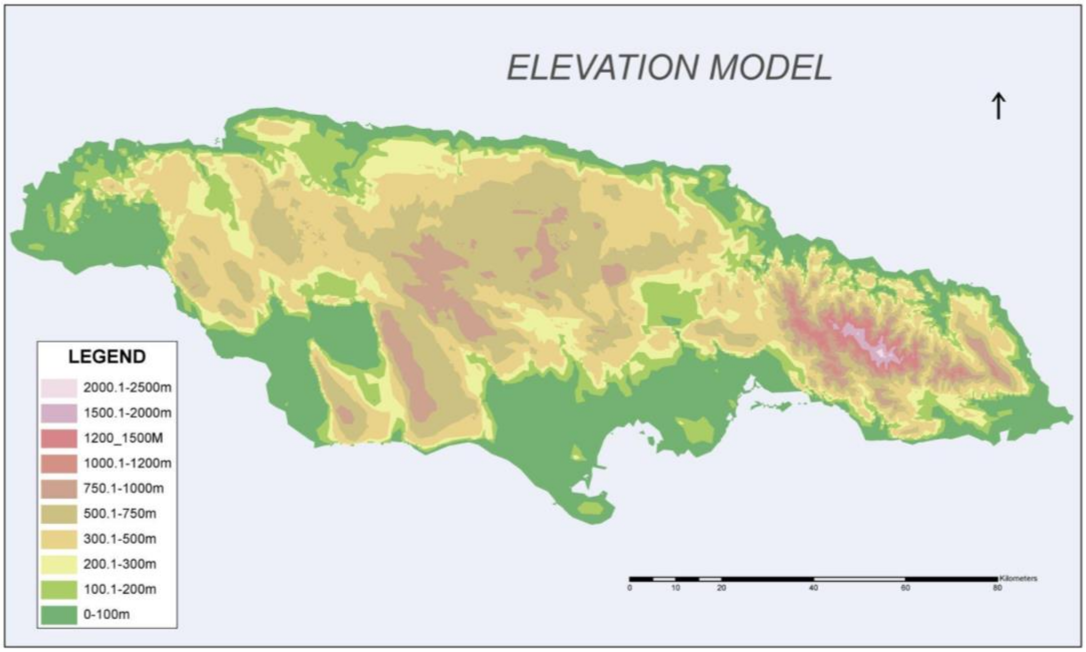

Figure 5. Digital elevation model (DEM) of Jamaica (Source: ESRI Open Data).

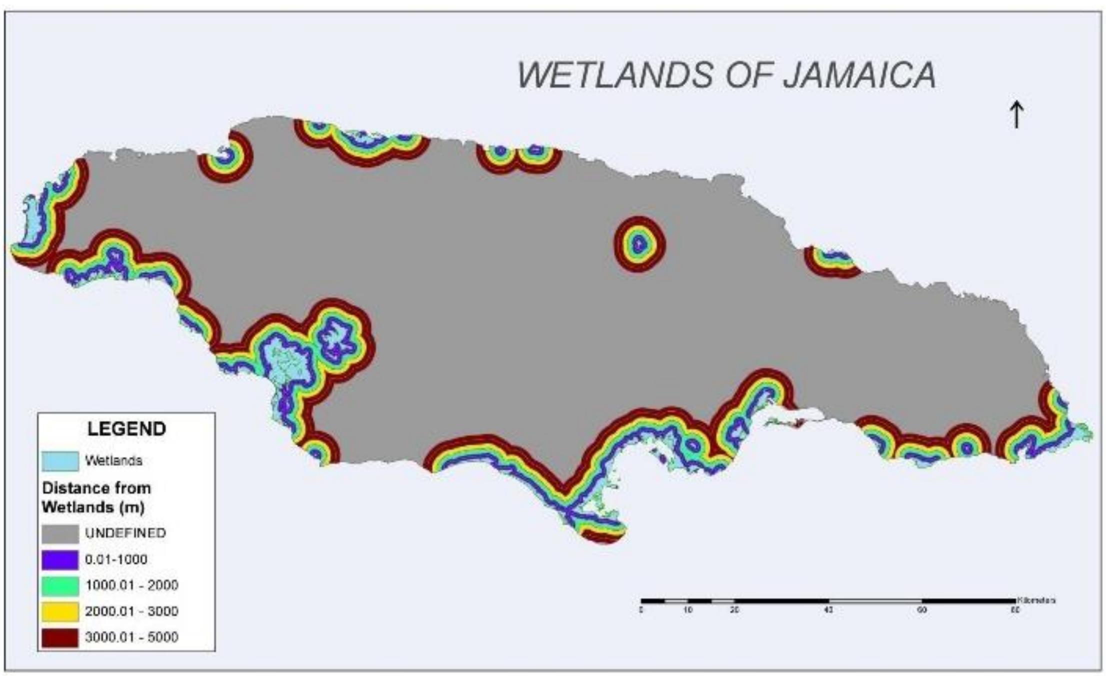

Figure 6. Map showing wetland areas in Jamaica (Source: Forestry Department, Jamaica).

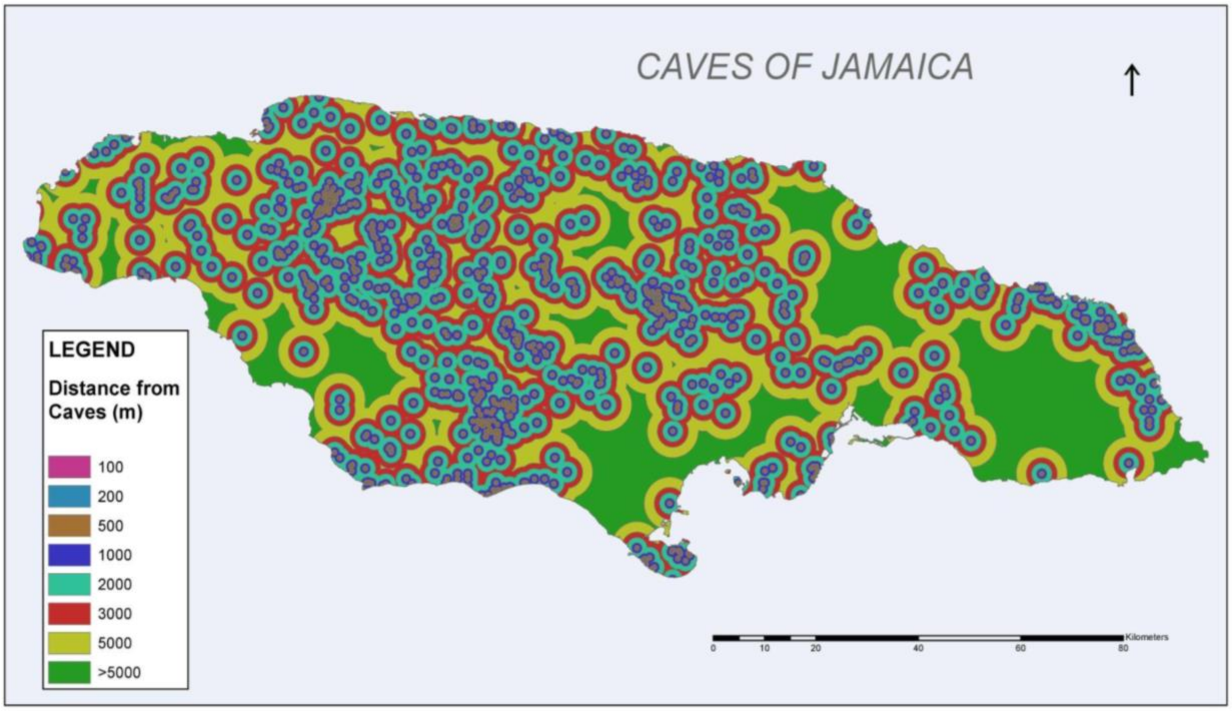

Figure 7. Map showing cave locations in Jamaica. The buffers used in the mode have been included (Source: Jamaica Caves Organization).

The digital elevation model (DEM) shows the relief of the island and will aid in site distribution as indicated and recorded in the various field notes and publications (e.g., Allsworth-Jones 2008; Atkinson 2019).

Equal Weights Model

The equal-weights predictive model shows some interesting results (**Figure 8**). Recorded Pre-Columbian sites were then plotted to show how well the equal-criteria weighted model captured the current distribution of sites. The model is divided into four distinct classes which range from poor to best (**Table 8**). For simplicity, only four ranking classes were used for the model even though the criteria subclasses were ranked from one to six. The model shows 57 (13.2%) of existing sites falling in the best class, 156 (36%) of sites in the good class, 167 (38.6%) in the satisfactory class and 53 (12.2%) of sites in the poor class. This means that the model is suggesting that about 12% of the sites are plotting in locations that do not fit the combined criteria and only 13% of sites fit the combined criteria. A closer look at this initial model generally mimics the site locations. Roughly 49% of Pre-Columbian sites were within areas defined as "best' or "good", with nearly 90% matching satisfactory to best. Forty-nine percent (213) of the sites fell within the predicted areas while just over 50% (220) of the sites fell outside the predicted locations. Given the fact that the model had all criteria equally weighted, meaning all criteria had the same level of importance in determining where Pre-Columbian sites were located, the distribution was successful.

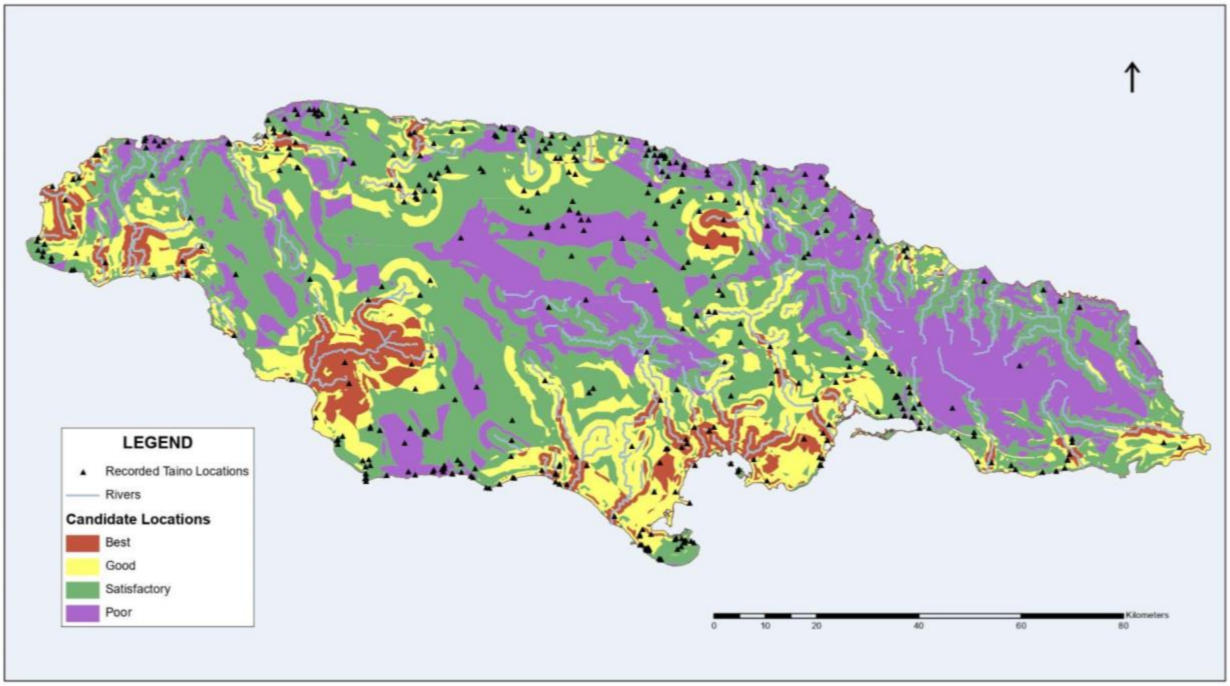

Figure 8. Map of Jamaica showing the results of the equal-weight predictive model of Pre-Columbian sites with an overlay of existing sites.

Table 8. Results table for equal-weights predictive model.

Score	Ranking	Category	No. of Sites	% of Sites
0.1666 - 2.3324	1	Best	57	13.2%
2.332401 - 2.9988	2	Good	156	36%
2.998801 - 3.6652	3	Satisfactory	167	38.6%
3.665201 - 5.1646	4	Poor	53	12.2%

Sensitivity Analysis

To determine the model's sensitivity to each criterion, each criterion feature class was removed, and a new model generated. How the model responded to the absence of a feature class i.e., changes in the distribution and areal cover of predictive locations, was used as a proxy to ascertain the importance of each criterion. Rankings were established from these observations.

The model shows a reduction in the areal extent of poor sites when the coastline buffer was removed (**Figure 9A**). The coastal buffer had a negative effect on the predicted model (**Table 8**). The removal of the coastline buffer only increased the number of sites in the predicted areas by 16% in the best and good categories and reduced the number of poor sites by 6% (**Table 9**). This suggests that the impact of the coastline on the model becomes less significant when given any weight greater than zero (0).

The model reflects a sensitivity to elevation as 34 (7%) additional sites were added to the predicted areas in the best category. However, it was observed that the equal weights percentages (**Table 8**) and the sensitivity analysis for elevation were 49% and 48%, respectively (**Table 9**). This suggests that elevation is a factor for Pre-Columbian populations in the selection of their habitable locations (**Figure 9B**).

The removal of the river feature class increases the areal extent of the poor candidate locations, particularly in the central, eastern, and north-eastern sections of the island (**Figure 9C**). This suggests that rivers or the availability of fresh water was a major feature in settlement site location. The model shows an increase in the number of sites in the good and best categories (**Table 9**). This suggests that river is a factor for Pre-Columbian populations in the selection of their habitable locations (**Figure 9C**).

Geology is a significant feature for Pre-Columbian settlements as a large proportion of the island became poor locations when this feature class was removed (**Figure 9D**). This was evident in the interior from St. Ann in the north to the coast of St. Elizabeth and Manchester in the south and much of Portland and St. Thomas. 19% of sites were now associated with unlikely locations for settlement (**Table 9**).

The removal of the wetlands feature class reduced the areal extent of poor site locations (**Figure 9E**). Central, north-eastern, and eastern Jamaica and a small section of St. Elizabeth along the coast showed poor site locations. There were approximately 20% of sites now located in areas classified as best (**Table 9**).

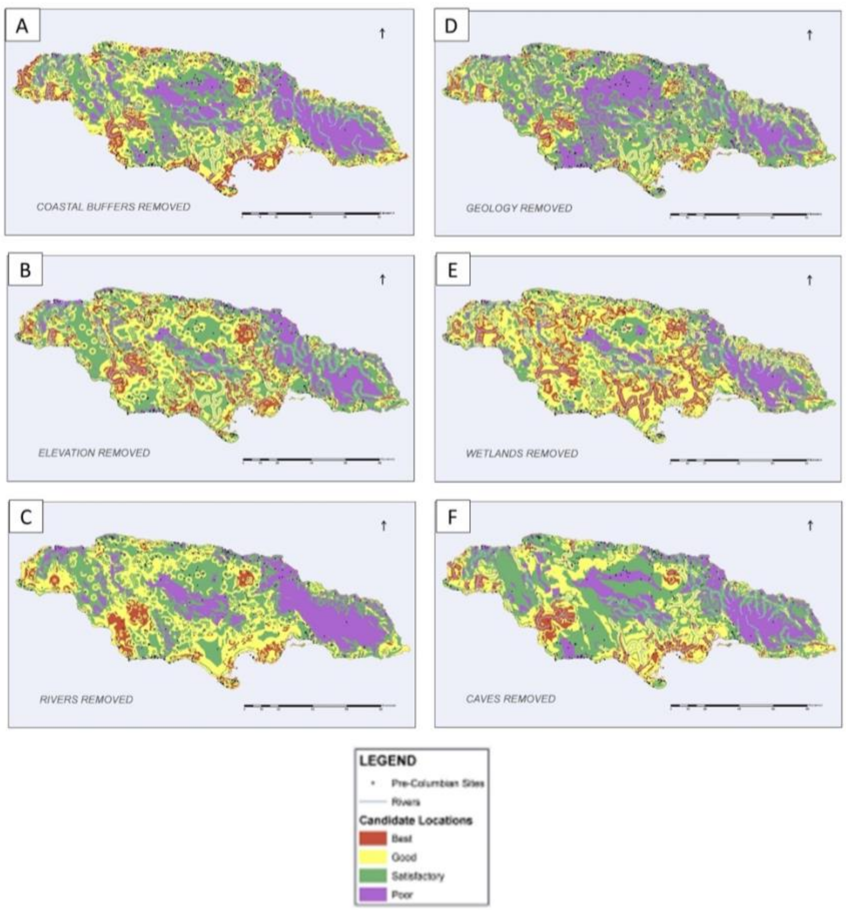

Figure 9. Results of the sensitivity analysis performed on the equal-weights predictive model. A-Coastal, B-Elevation, C-Rivers, D-Geology, E-Wetlands, F-Caves.

Table 9. Summary table of the sensitivity analyses: A-Coastal, B-Elevation, C-Rivers, D-Geology, E-Wetlands, F-Caves.

A-Model without Coastal Buffers				
Score	Ranking	Category	No. of Sites	% of Sites
0.2 - 2.4	1	Best	101	23.3%
2.401 - 3.2	2	Good	182	42%
3.201 - 4	3	Satisfactory	123	28.4%
4.01 - 5.8	4	Poor	27	6.2%

B-Model without Elevation				
Score	Ranking	Category	No. of Sites	% of Sites
0.6 - 2.6	1	Best	91	21%
2.601 - 3.2	2	Good	117	27%
3.201 - 4.0	3	Satisfactory	180	41.6%
4.01 - 5.6	4	Poor	45	10.4%

C-Model without Rivers				
Score	Ranking	Category	No. of Sites	% of Sites
0.2 - 2.2	1	Best	62	14.3%
2.201 - 3	2	Good	177	40.9%
3.01 - 3.8	3	Satisfactory	150	34.6%
3.801 - 5.4	4	Poor	44	10.2%

D-Model without Geology				
Score	Ranking	Category	No. of Sites	% of Sites
0.2 - 2.4	1	Best	50	11.5%
2.401 - 3	2	Good	118	27.2%
3.01 - 3.8	3	Satisfactory	183	42.3%
3.801 - 5.6	4	Poor	82	19%

E-Model without Wetlands				
Score	Ranking	Category	No. of Sites	% of Sites
0.2 - 2.2	1	Best	87	20.1%
2.201 - 3	2	Good	195	45%
3.01 - 3.6	3	Satisfactory	126	29.1%
3.601 - 5	4	Poor	25	5.8%

F-Model without Caves				
Score	Ranking	Category	No. of Sites	% of Sites
0.2 - 2.2	1	Best	53	12.2%
2.201 - 3	2	Good	155	35.8%
3.01 - 3.8	3	Satisfactory	167	38.6%
3.801 - 5.2	4	Poor	58	13.4%

Table 10 shows the summary data for the sensitivity analysis. It shows that geology was ranked as the most significant criteria and caves were the least significant criteria (**Figure 9F**). These ranks were determined from speculating the data obtained from the sensitivity analysis. Geology recorded the most significant increase in poor sites when removed from the model.

Analytical Hierarchy Process (AHP) Model

After electing a rank for each criterion (**Table 10**), a structured approach was necessary to determine their respective weights (Saaty 1987). The analytical hierarchy process (AHP) model was adopted to weigh each criterion, where the relative importance of each criterion was determined using the Saaty (1987) pair-wise comparison matrix. To ensure the validity of the weightings or hierarchy, a consistency ratio of 0.022 was calculated. A ratio above 0.1 signifies a departure from consistency and calls for re-evaluation of their relative importance. **Table 11** shows the resultant ranking.

Table 10. Summary table showing the new rank of the criteria using the results of the sensitivity analysis and Saaty (1987).

Criteria	Rank
Geology	1
Elevation	2
Rivers	3
Wetlands	4
Coastline	5
Caves	6

Table 11. Pairwise matrix for the AHP after Saaty 1987.

Criteria	Geology	Elevation	Rivers	Wetlands	Coastline	Caves	Total Score
Geology	1	2	3	5	7	9	**27**
Elevation	1/2	1	2	4	6	8	**21.5**
Rivers	1/3	1/2	1	3	4	6	**14.833**
Wetlands	1/5	1/4	1/3	1	2	4	**7.783**
Coastline	1/7	1/6	1/4	1/2	1	2	**4.0596**
Caves	1/9	1/8	1/6	1/4	1/2	1	**2.1526**

Table 12. The weighted values for each criteria from the AHP analysis.

Criteria	Total Score	Weight	%
Geology	27	0.3491611081	34.9%
Elevation	21.5	0.2780356972	27.8%
Rivers	14.833	0.1918187673	19.2%
Wetlands	7.783	0.1006489224	10.1%
Coastline	4.0596	0.05249831239	5.2%
Caves	2.1526	0.02783719264	2.8%
Total	77.3282	1	100.0%

The weights in **Table 12** were used to generate the weighted suitability model for Pre-Columbian locations using Equation 2.

(2) *Weighting = [0.349 x Geology Rating] + [0.278 x Elevation] + [0.192 x Dist. from Rivers Rating] + [0.101 x Dist. from Wetlands Rating] + [0.052 x Dist. from Coast] + [0.028 x Dist. from Caves]*

The new ranking from the AHP was used to generate a new predictive model (**Figure 10**). The existing Pre-Columbian sites were then plotted as an overlay to show how well the weighted suitability model captured the current distribution of sites. Approximately 74% of Pre-Columbian sites fall within the "best" and "good" categories of the model (**Table 13**). Using Equation 2, a dot distribution map was generated to compare existing and potential Pre-Columbian settlement locations (**Figure 11**). This was done to 1) judge the accuracy and reliability of the model and, 2) identify other candidate sites for possible exploration.

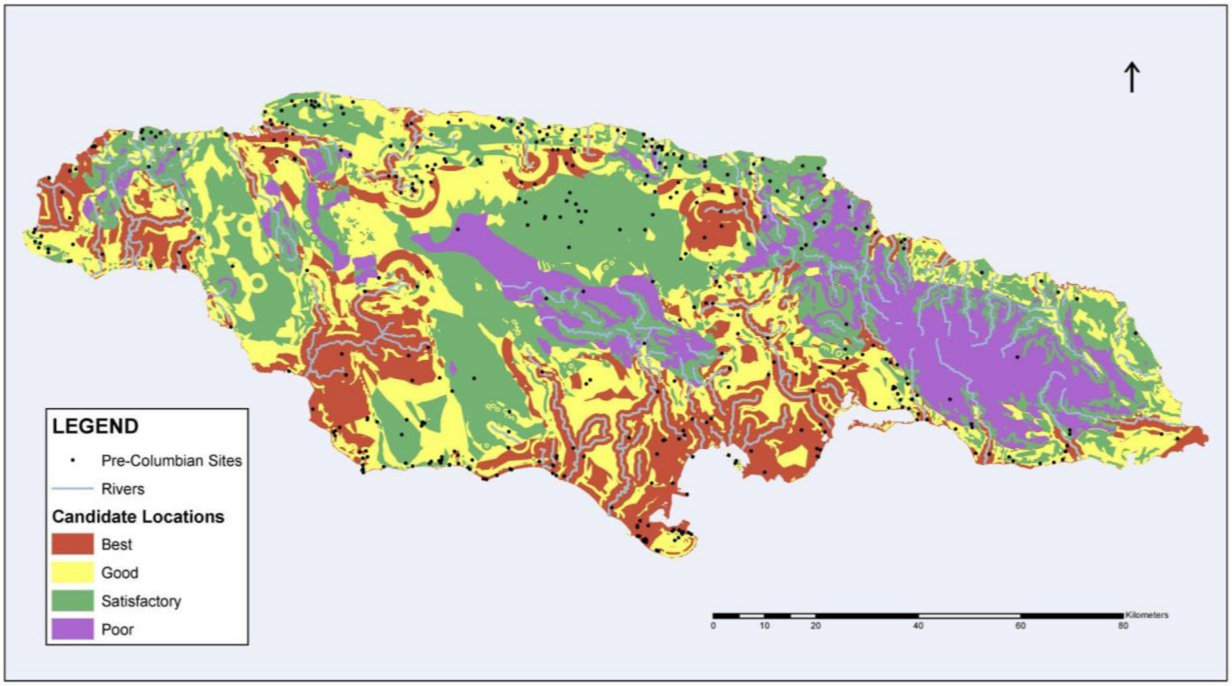

Figure 10. Map of Jamaica showing the predictive model using ranking generated using AHP. The existing Pre-Columbian sites are added as an overlay.

Table 13. Summary data for the predictive model using the AHP.

Score	Ranking	Category	No. of Sites	% of Sites
0.278 - 2.335	1	Best	149	34.4%
2.33501 - 3.133	2	Good	171	39.5%
3.13301 - 4.081	3	Satisfactory	102	23.6%
4.08101 - 5.652	4	Poor	11	2.5%

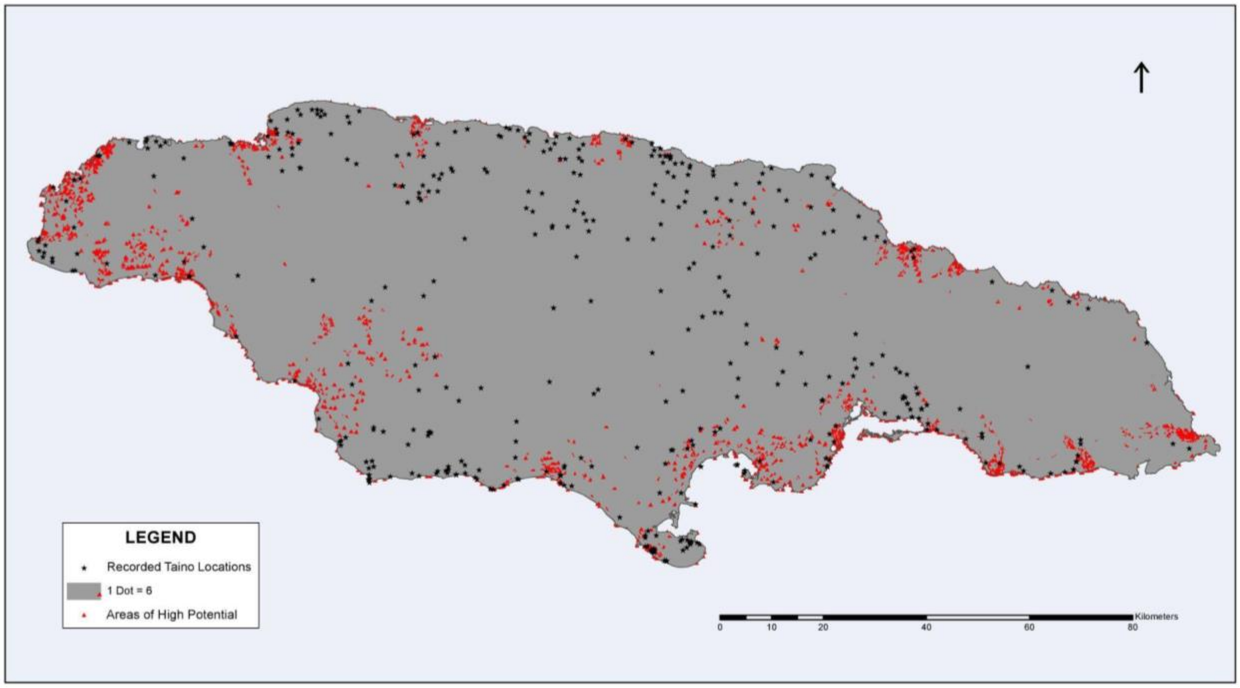

Figure 11. Dot map extracted from the predictive model produced using weights from the AHP.

Discussion

The results of the predictive modelling indicate geology is the most important criteria for the selection of Pre-Columbian settlement sites. The influence of geology/lithology in this study suggests the importance of natural resources such as soil type, texture, and the associated natural vegetation. Geology would be important to Pre-Columbian settlers as this would impact topography which is important for lines of defence; arable land for cultivation; rocks for making stone tools and clay source for pottery. Elevation was also found to be a significant criterion for settlement. This result is consistent with Atkinson's database (2019), as it was observed that 90% of the sites were found at elevations between 0 and 500 m. The occurrence of sites over 500 m was small in comparison to the lower elevations.

Distance from the coast appears to be one of the least important criteria. This observation is particularly interesting as the proximity to the coast has traditionally been viewed as an important site location factor. It would be interesting in future explorations to determine if this variable is influenced by cultural classifications such as Ostionan versus Meillacan. The importance of geology/lithology over natural resources such as proximity to rivers is indeed revealing. Perhaps it reflects an underestimation of previous scholars of the key factors that influences the site locations. The proximity of riverine resources has been tied to subsistence reasoning such as access to fresh water and food resources. Caves were the least important criteria which showed negligible results during the sensitivity analyses. This could be because site selection depended on geology and elevation to a larger extent and finding a cave was probably a bonus.

The ultimate test of this model would be ground truthing exercises of select sites. This will enable exploration activities to determine if the predicted site does in fact show evidence of habitation or temporary presence.

Conclusion

This study demonstrates that significant input of high-resolution data is required to generate models that can predict the locations of Pre-Columbian sites in Jamaica. The analysis provides a preliminary list of sites that can potentially be explored and excavated. The complex geology and intricate drainage patterns of Jamaica suggests that a repeat of this study at a smaller scale, by parish or by county may allow for better accuracy and better discrimination of buffers. It is to be noted that the resolution of the data presented the greatest limitation. None the less, these initial results are a springboard for future work both in Jamaica and across the Caribbean, provided data is available. The site distribution also allows for land use planning and watching briefs as development activities continue across the island.

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