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THE USE OF GEOSTATISTICAL METHODS TO PREDICT ARCHAEOLOGICAL SITES ON THE BORDER BETWEEN PARANÁ AND SÃO PAULO, BRAZIL

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REVISTA ARQUEOLOGIA PÚBLICA

ABSTRACT

The purpose of this paper is to discuss landscape differences that may have influenced pre-colonial human occupation and predict where activities took place in a now modified environment. The findings, considering past human occupation, suggest important landscape differences. From a predictive point of view, the existence of a boundary between the archaeological sites of Paraná and São Paulo, so far unconfirmed, was ratified.

KEYWORDS: Prediction; Border; Geostatistics; Archeology; Paraná; São Paulo

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RESUMO

O objetivo deste trabalho é discutir diferenças paisagísticas que podem ter influenciado a ocupação humana pré-colonial e prever onde as atividades tiveram lugar num ambiente agora modificado. Os resultados, considerando a ocupação humana passada, sugerem importantes diferenças paisagísticas. De um ponto de vista preditivo, a existência de uma fronteira entre os sítios arqueológicos do Paraná e São Paulo, até agora não confirmada, foi ratificada.

PALAVRA-CHAVE: Predição; Fronteira; Geoestatística; Arqueologia; Paraná; São Paulo.

RESUMEN

El propósito del presente trabajo es discutir las diferencias paisajísticas que podrían haber influido en la ocupación humana precoloniales y predecir en qué lugares se desarrollaron las actividades en un entorno que en la actualidad se encuentra modificado. Las conclusiones, considerando la ocupación humana pretérita, sugieren importantes diferencias paisajísticas. Desde el punto de vista predictivo, se ha ratificado la existencia de un límite entre los sitios arqueológicos de Paraná y São Paulo, que hasta ahora no habían sido confirmadas.

PALABRAS CLAVE: Predicción; Frontera; Geoestadística; Arqueología; Paraná; São Paulo

1. Introduction

Studies carried out since the 1960s in the Paranapanema River brought new data on the presence of archaeological traditions forged by the taxonomy produced by Igor Chmyz in Paraná (1976), and many archaeological sites were classified with variations in their composition over these years until the São Paulo margins (CHMYZ et al., 2008).

According to the descriptions made of the artifactual sets that represent the Umbu, Itararé, and Tupiguarani technological complexes, the distribution of the sites was made according to the spatiality, considering in depth the configurations of the environmental conditions or the nuances present between possible human contacts and the influences of the environment in the retention of human groups in this area of the Paranapanema River.

Considering that the Paranapanema region is currently seen as a point of attraction for several human groups in the pre-colonial period with routes from various parts of Brazil and neighboring countries, the objective of this work is to test the hypothesis that there is a difference in spatiality distribution of archaeological sites allocated between Paraná and São Paulo so that they shape the different human behaviors based on response to environmental variables that influence cultural interactions in the area.

This hypothesis has an important meaning because working on a micro-scale, territoriality is seen as a determining element in taking decisions on routes, forms of spatial dispersion, behavior modification with regard to movement in the territory and questions about possible limitations, being able to increase the scale of analysis that places the influence of human agents involved in decision-making.

The current state of research tends to review the literature due to the great influence of PRONAPA's management in the research area during the 20th century. However, there was a strong tendency to review the bibliography caused by the change in the way of looking at the formulation of how knowledge about the subject was produced based on linguistic, historical, and ethnographic sources.

New studies have been produced, and new research perspectives bring results that surpassed the prevailing conception of demography and geographic distribution and focus on indigenous history reconsidered by archaeologists who have been focusing on an archaeological review mainly concerning the Kaingang and Xokleng populations (SALDANHA 2008; COPER, 2006; DE MASI, 2006; IRIARTE & BEHLING, 2007).

Other studies also re-elaborate and review studies concerning Umbu technological complexes from a non-historical approach to the issue. OKUMURA and ARAÚJO (2014) contest that such a large period and a vast territory encompassing Umbu groups, suggesting the existence of a single archaeological tradition, so that greater diversity within this tradition would result from regional specificities. The Itarare are being extensively revised as per (NOELLI & SOUSA, 2017) to reassess a link between past and present through linguistic connections and material culture.

Regarding the Tupi-Guarani, although studies have become more commonplace because they are groups that exist until the present day, there is still much controversy in how they are studied, with some confusion regarding their spatial dispersion and the study of material culture.

Since the establishment by PRONAPA, there have been many differences in how these technological complexes were studied, rethinking the standard model on territoriality and demography. This influence marked eminent considerations on the technological complexes Umbu, Itarare, and Tupi-Guarani, with considerations of different degrees of forms of space occupation according to their artifactual repertoires.

The geographic distribution was carried out in function of these technological complexes, with little regard for the relationships between these technological complexes and the landscape geographic variables. There were hypotheses on how human groups behaved in landscapes, but no cartographic aspect was explored to express territorial contradictions.

The concern was with the reaffirmation and validation of a taxonomy based on the study of a few archaeological sites and with interventions based on the opening of surveys that considered stratigraphy and material culture representing a generalized classification of human culture.

The main objective of this work is to bring out the spatial relationships established between past human groups on the border between Paraná and São Paulo for three technological complexes, Umbu, Itararé, Tupi-Guarani, and to verify if geographic variables can clarify to what extent this area impacts the behavioral factors of human groups.

The main conclusions are that there are differences due to altimetry and distance from watercourses, so that archaeological sites present a differentiated spatial distribution, with two standard behaviors: as a function of altimetry for Umbu sites and non-affiliated lithic sites, and a greater generalization for Itararé groups, and little influence on Tupi-Guarani groups.

2. Materials and methods

It was decided to carry out the procedures under the concept of Free GIS, whose fundamental ethical principle is Free Geoinformation, that is, cartographic products resulting from a GIS (Geographic Information System) cycle that employs the acquisition of spatial data to the use of geoalgorithms, written in open source codes, freely shared (RIZZI, 2017).

Following the Free GIS principle, all data were obtained free of charge from official websites of Brazilian public institutions. For the generation of the analyses, the free software of Geoprocessing QGIS and SAGA were used.

For the cartographic study, a universe of 256 archaeological sites classified by their mentioned types was obtained. We investigated the possibility that environmental variables, altimetry (contour lines), and the distance to closer water bodies could be related to the distribution of the sites.

For altimetry, SRTM raster images were used, joints SG-22-XA, SG-22-XB, SG-22-XC, SG-22-XD, and SF-22-ZD with a spatial resolution of 90 meters, at a scale of 1:250.000 whose Geographical Coordinate System Datum: WGS-84 was converted to the current model SIRGASS 2000. These images were taken from the website of the Brazilian Agricultural Research Corporation - EMBRAPA (EMBRAPA, 2008).

The universe of rivers and streams corresponding to the articulation area of the aforementioned SRTM images was extracted from the hydrography database, in the scales of 1:50,000 and 1:100,000, captured from the website of the National Water Agency - ANA (ANA, 2018).

For the detection of terrestrial landscapes where the sites predominate, the theme of Geodiversity of the Geodiversity Surveys of the States of Paraná, scale 1:1,000,000 and of the State of São Paulo, scale 1:750,000, as detailed as possible was used. They were obtained by the GeoSGB geoscience system available on the website of the Brazilian Geological Service of CPRM - Mineral Resources Research Company (CPRM, 2021).

The topological treatment step used console tools available in the QGIS Processing Toolbox, 3.16.5-Hannover. It was necessary to plan the assignment of numerical values for altimetry and proximity to the streams closest to the sites.

For altimetry, the altimetric values from the SRTM images were assigned to each of the 256 sites registered and available in the literature about the area (DeBLASIS, 1999-2000; ARAUJO, 2001; PARELLADA, 2004, 2005) using the Add raster values to points tool from SAGA 2.3.2. Then, the procedures for obtaining the value given in meters from the position of each of the 256 sites to the nearest stream or river were started. This procedure required a series of steps which were detailed as follows.

The extraction of hydrographic data used the orientation of the archaeological bibliography as a parameter, which states that fundraising for sites within a radius of up to 10km is typical. Thus, areas were generated by site position in influence buffers in that radius through the Create Buffer tool of the MMQGIS plugin.

From the hydrographic spatial database, the universe of target rivers and streams was cut, having their locations within these areas as a topological parameter. From the cut obtained, the hydrography was converted into a cloud of equidistant points in the order of 100x100m using the Convert lines to points tool from SAGA 2.3.2.

Using the tool Distance to the nearest central point (points) of QGIS, a second layer of hydrographic points was generated, this one containing a column with the distance given in meters to all sources (sites).

Next, the tool Distance to the nearest center point (line to center point) of QGIS was used to generate a matrix of lines with the shortest distances from the origin (sites) to the destination (hydrographic points).

A topological convergence between vertices of lines with smaller distances spatially associable to the resulting sites. Thus, we used the QGIS Extract Vertices tool to convert the vertices into points. Thus, the Numerical values of the minimum distances of the contact points with the sites that touch them were attributed by the tool Associate attributes by location of QGIS.

Thus, we obtained a column with the numerical values of the minimum distances for each of the 256 sites with each watercourse geographically closer.

The contribution of cartography to the archaeological study, in addition to offering visual representations, also provides forms of spatial analysis to observe possible distribution patterns of the sampled places.

Spatial Analysis is a set of techniques that should "pay special attention to the spatial arrangement of the geographic phenomenon and not to the phenomenon itself". Thus, the "where – the spatial distribution of phenomena – is the central objective of the space school" (FERREIRA, 2006, p.106).

The concept is based on the geospatial language of primitives, point, area, and line. In the intercourse of conversions between primitives, it seeks to identify the spatial relationships that can support analyses of other scientific narratives.

The spatial analysis is based on two basic principles for the construction of its spatial intelligibility: the site, which "has a similar meaning to the term substance [...] and consistent with the notion of geographical area " (FERREIRA, 2006, p.108) where its location - materialization of the site in space -, incorporates the "local characteristics described by chronological attributes", such as "the population, the number of cases of a contagious disease, for example" (FERREIRA, 2006, p.110).

The site under spatial analysis is also seen as a vertical conduit for "the defining characteristics of a place, that is, demography, industry, health, climate, transport and violence, among others" (FERREIRA, 2006, p.107).

Vertical because their existence is the result of the action of cultural agents or natural phenomena: they are independent variables. Each site/location has another fundamental attribute in Spatial Analysis: the situation. It is impossible to separate the site from the situation: "The situation, as opposed to the notion of site, is horizontal and is associated with properties of "regional interdependence, connections between places and spatial integration" (FERREIRA, 2006, p.107).

It is the dependent variable that seeks to explain/describe/reveal. Spatial analysis techniques seek to extract the situation of the universe of the studied sites/locations. The site principle is the starting point, par excellence, as "it is the place or observational unit of the characteristic, for example, the municipality, the health district, the hospital or the residence where dengue cases were confirmed" (FERREIRA, 2006, p.110).

The positions of archaeological sites are locations related by parameters of proximity, neighborhood, and spatial correlation. The analyses generated from the use of the sampled positions seek to qualify and quantify the locations of the sites, that is, to show spatial relationships that the archaeological narrative may deem relevant to its field of study. For this purpose, the ability of spatial relationship between the geoobjects given by the analysis was used, which resulted in predictive mappings for detecting spatial patterns of occupation in the universe of target sites.

The Inverse Distance Weighted interpolator, IDW – Inverse Distance Weighted, from QGIS was chosen. It is a local and deterministic interpolator. Its adoption is due to the consideration that the radius of fundraising for a site is around 10km, guiding the choice of an interpolator whose prediction hypothesis implies that local effects for the phenomenon predominate.

Based on deterministic modeling, that is, when “each point on the surface is estimated only from the interpolation of the closest samples, using a function as the inverse square of the distance” (CAMARGO et al, 2002, p.3-2), the interpolator calculates the value of a point averaging with the nearest points to obtain the inverse distance-weighted average.

The formula used to the modeling is: $Z= (zi -z)^2$. Where Z: the interpolated value; n: the number of observed geoobjects; zi: corresponding to the values assigned to the geoobjects, and di: the observed distance between the geoobjects and the interpolated value (zi and z). The estimator also offers the possibility of adjusting the value of the power “p” of interpolating the values. The greater the power adjustment “the greater the influence of the nearest neighbor in the estimation of values.” (VARELLA & SENA JUNIOR, 2008). We kept the “p” value adjusted according to the previous geoalgorithm configuration.

The SAGA tool Multiple Regression Analysis (Points and Prediction Grids) was used to validate the predictive models. Two tests were performed. The geostatistical validation of the Correlation Coefficient test (r^2) obtained a result of 0.9 both for the altimetry trend surface and for the proximity-distance relationship to the closest watercourses, confirming that both models come from the numerical values obtained.

The Pearson Coefficient test, P-value or p-value Geostatistical Significance Test, which measures the probability of the model being a result or not of the values used, resulted in a value of 0 for both models, confirming the regression equation. Therefore, the multiple had good adequate significance for the predictions of the generated surfaces.

3 – Results

As shown in Map 01, the classification was performed using the Quartile Method for the numerical values of altimetry and hydrography.

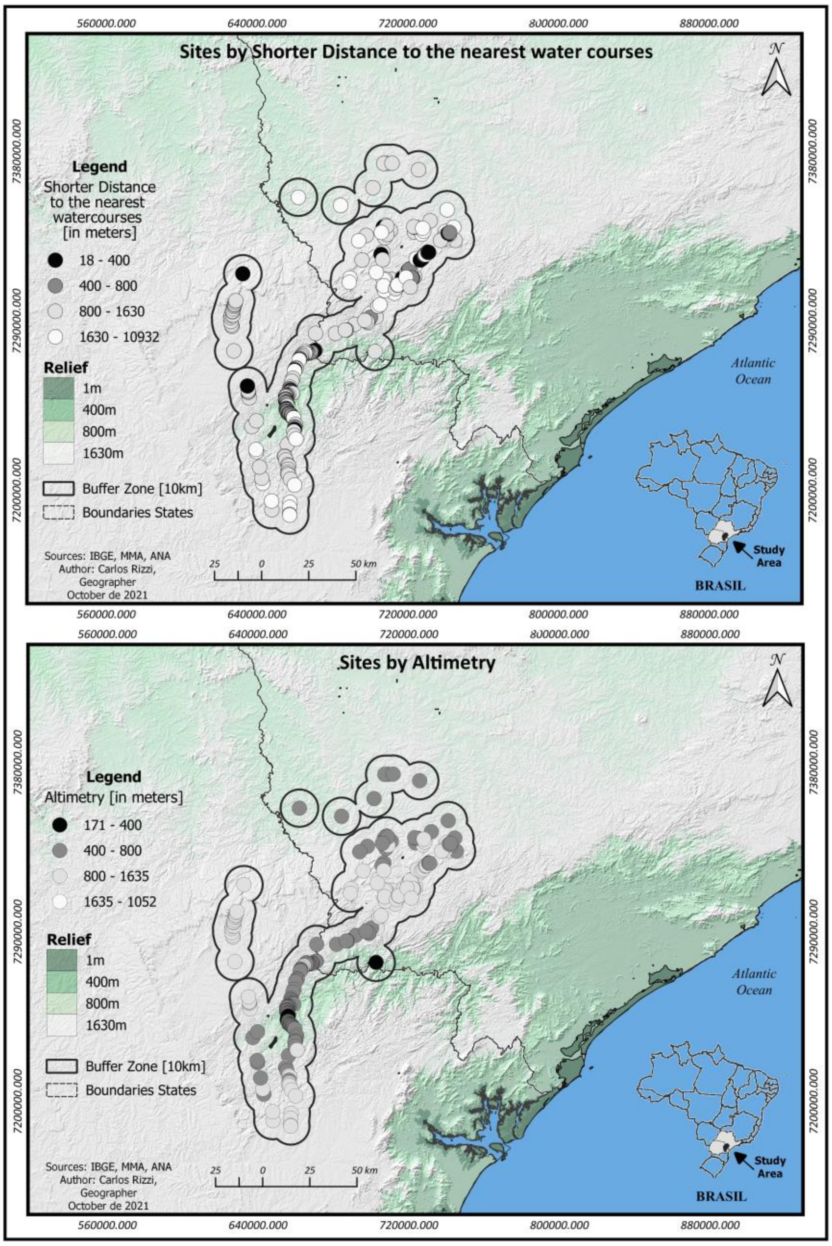

Figure 1 – Sites by altimetry and shorter distance to nearby water courses

As shown in Map 02, the modeling of the points interpolator applied to the universe of 256 archaeological sites classified by the Quartile Method was carried out for the numerical values of altimetry and hydrography.

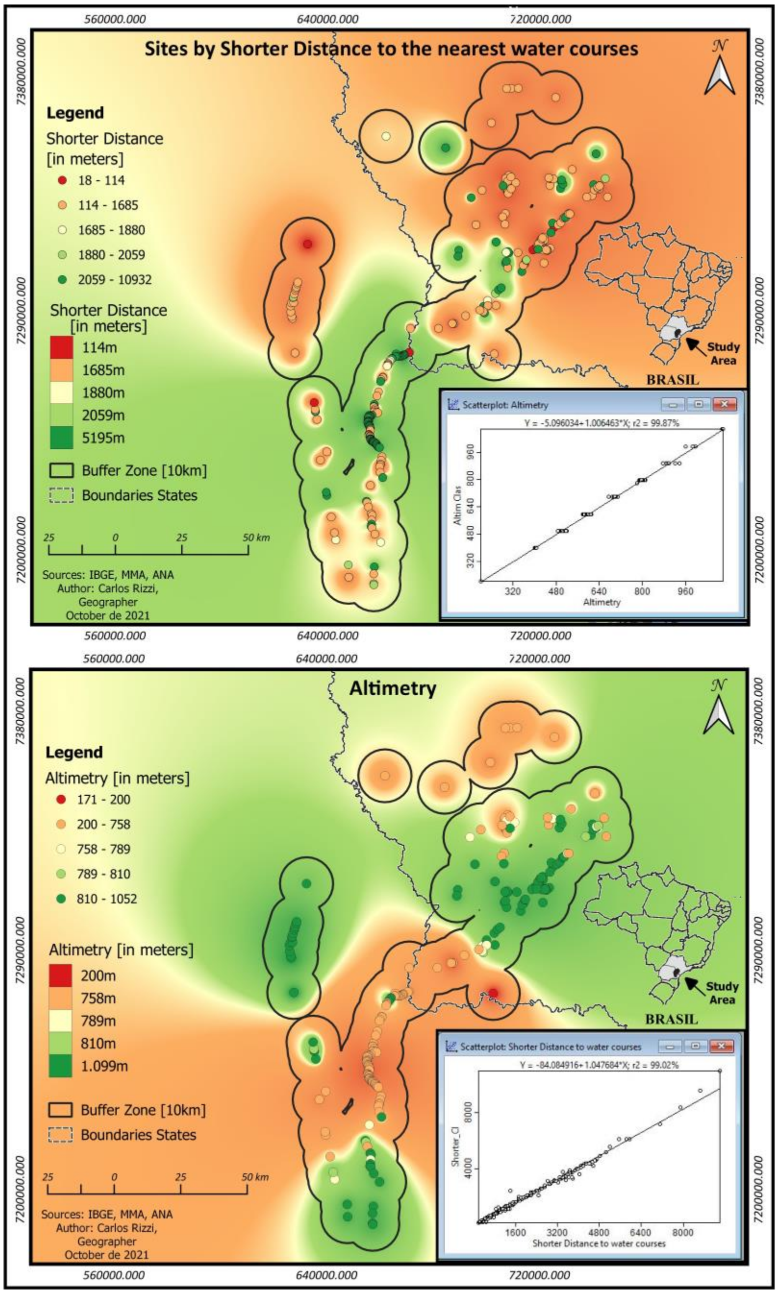

Figure 2 – IDW modeling of sites by altimetry and shorter distance to nearby water courses

The comparison between the results of the interpolations denotes, as shown in Map 02, the existence of two spatial patterns of distribution.

By interpolating the altimetric values, it is possible to perceive to the south a spatial pattern of sites (79 of the Itararé type equivalent to 30.9% of all sites) located at elevations of up to 800 meters in altitude. To the north of the map, we notice a pattern of sites (32 of the lithic type, equivalent to 12.5% of all sites) located at elevations from 800 to 1,000 meters in altitude.

With hydrography, the opposite occurs. While we have a “southern” pattern where sites (79 or 30,9%) are located between 2,000 and 3,000 meters apart, we have, in the north, another pattern where sites (32 or 12,5%) are not more than 1,600 meters away from the nearest watercourses. This distribution leads us to analyze the internal patterns by altimetry ranges and the relationship between proximity and distance to the closest watercourses.

As shown in Figure 3, when it comes to the distribution of sites by altimetry ranges, the concentration of Lithic-type sites (32) between the 700 to 1000 meter ranges is highlighted. The relationship between the number of sites and the distribution by strips also shows that the Itararé-type sites (79) are the ones that most appear and are present in all strips, ranging from 200 to 1,100 meters above sea level. The Umbu (8) and Tupi-Guarani (1) sites also appear from the 500m range, but to a lesser extent.

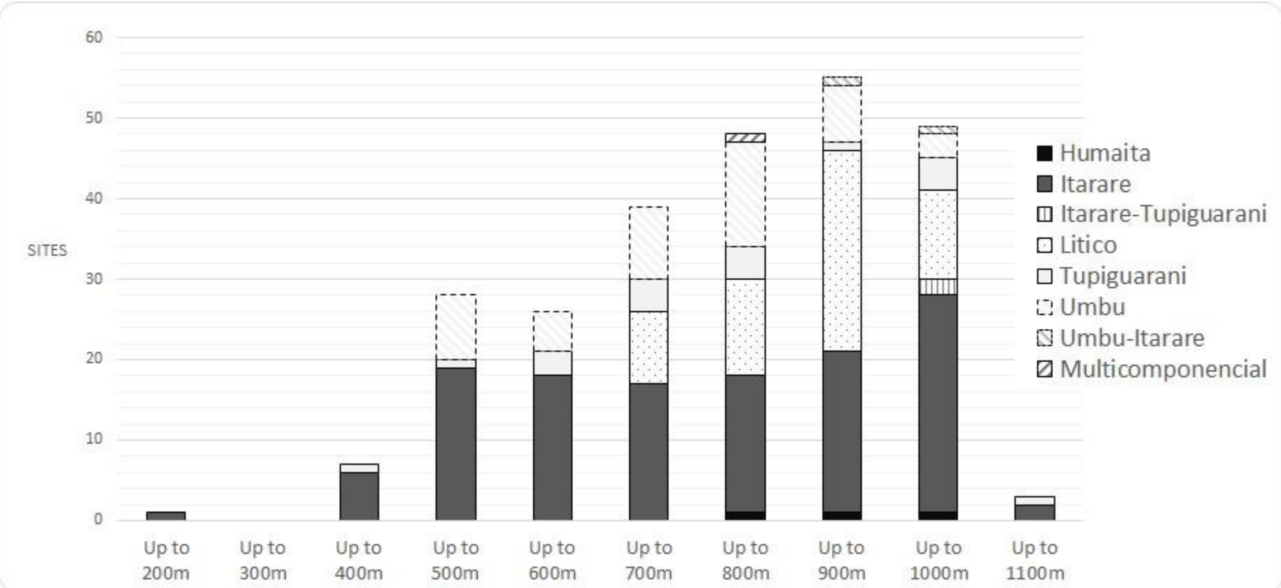

Figure 3 – Sites by altimetry tracks (100 x 100m)

The spatial distribution of Lithic sites led us to investigate possible spatial relationships between the distribution of site types and their average distances in relation to the closest watercourses.

The tabulation shown in Figure 4 denotes that most site types are located no further than 2,500 meters from nearby watercourses. The type of Umbu-Itararé site, spatially relating its data in Figure 3 and 4, shows that its former occupants chose high elevations but very close to water streams to settle in the landscape.

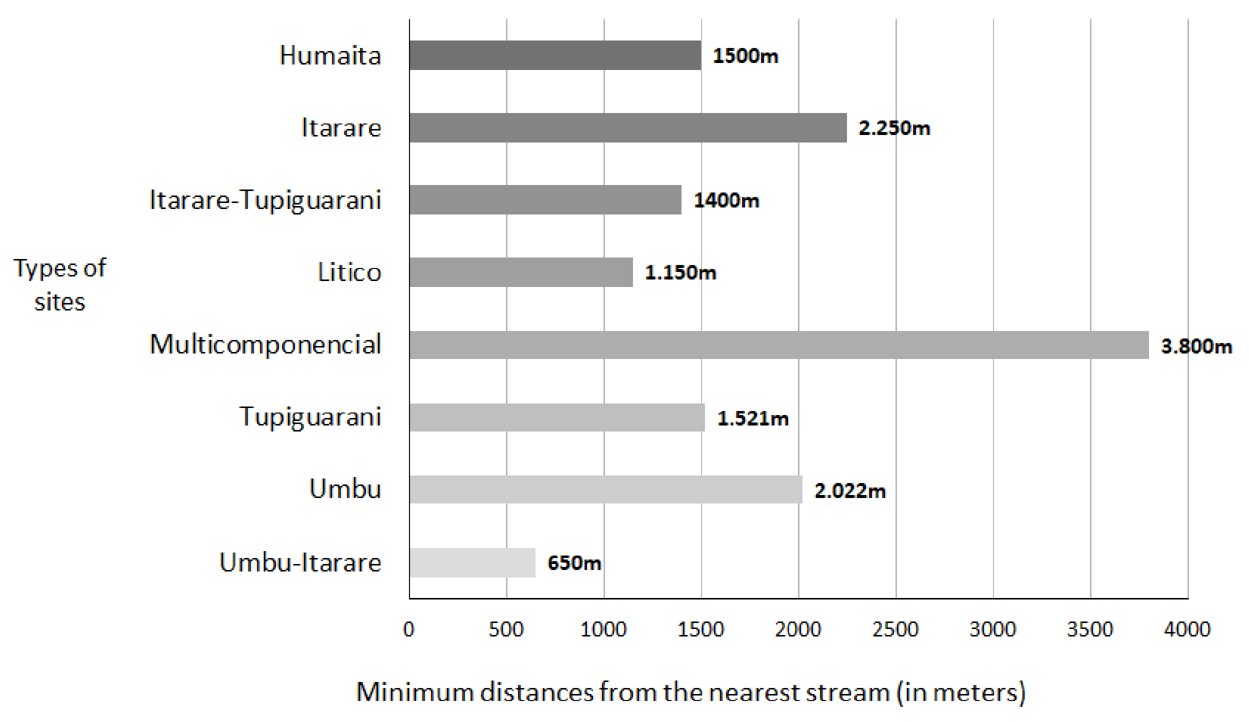

Figure 4 – Average minimum distances from sites to the nearest streams respectively (in meters)

Regarding the distance to watercourses, the Multicomponential type stands out. This is represented by only one case and differs from the other 255 sites sampled as it is 3,800 meters away from any nearest stream or river.

Lithic-type sites, as already noted, are positioned in high environments but seek locations close to water courses on average within a radius of no more than 1,500 meters away. The Itararé site type is well distributed in all altimetry ranges, and it established an average distance of less than 2,500 meters to distance itself from water courses.

We sought to detect the behaviors for each of the types of sites. The result can be seen in Figure 4. It is noteworthy that the vast majority of sites are located at a distance of up to 1,500 meters from the closest watercourses.

We tried to characterize the landscapes where the sites are located. For this purpose, the vector analysis Associate attributes by location of QGIS was used to link the location of archaeological sites to their respective terrestrial landscapes.

We can observe in Table 1 the distribution of the universe of sites by terrestrial landscapes. As a main result, the classification of site density by landscape units denotes a high concentration of 204 (79.69%) of the 256 sites, of which 134 were detected in the Low Hill and Hills Domain (52%), followed by 70 sites located in the landscape of the Domain of Dissected Hills and Low Hills (27%).

Table 1. Concentration of sites by Landscape Units

Concentration of sites	Domain of Hills and Low Mountains	Domain of Dissectised Hills and Low Hills	Domain of Broad and Gentle Hills	Mountainous Domain	Structural Steps and Erosive Edges	Mountain Escarpments	Chapadas end Plateaus	Total
Itarare	79	20	16	10	3			128
Litico	12	32	4	5	1	2		56
Umbu	35	9			1			45
Tupiguarani	6	6	6		1			19
Humaita	2	1						3
Itarare-Tupiguarani		2						2
Umbu-Itarare					1		1	2
Multicomponencial						1		1
Total	**134**	**70**	26	15	7	3	1	256
	52%	**27%**	10%	6%	3%	1%	0%	100%

Source: CPRM. Org. Carlos Rizzi.

Table 1 – Concentration of sites by landscape units: Source, CPRM. Org. Carlos Rizzi

From what is shown in Table 1, the cut was further delimited, having as a parameter the areas of the two landscapes where archaeological sites predominate. A more panoramic observation scale was applied using the articulation of raster images as a delimiting perimeter.

Based on the observation of the modeling and the reading of the relationships between the environmental variables, the limits of the hydrographic influence edges were applied to determine the set of altimetric dimensions corresponding to the possible occurrence areas of the two spatial patterns of distribution of the sites.

For the northern sector of the study area, the altimetric elevations located between the ranges from 800 to 1,000 meters above sea level and which are located up to 800 meters from the central axis of the rivers were delimited. For the southern sector, altimetric elevations of up to 800 meters of altitude were delimited, which lie exclusively within the 2,000 to 3, 000-meter ranges of the nearest rivers.

As we tried to carry out predictive mapping, we sought to expand the observation scale to monitor the occurrence of the same combinations of environmental variables in other parts of the study area and whether the presence of sites would be noticeable there.

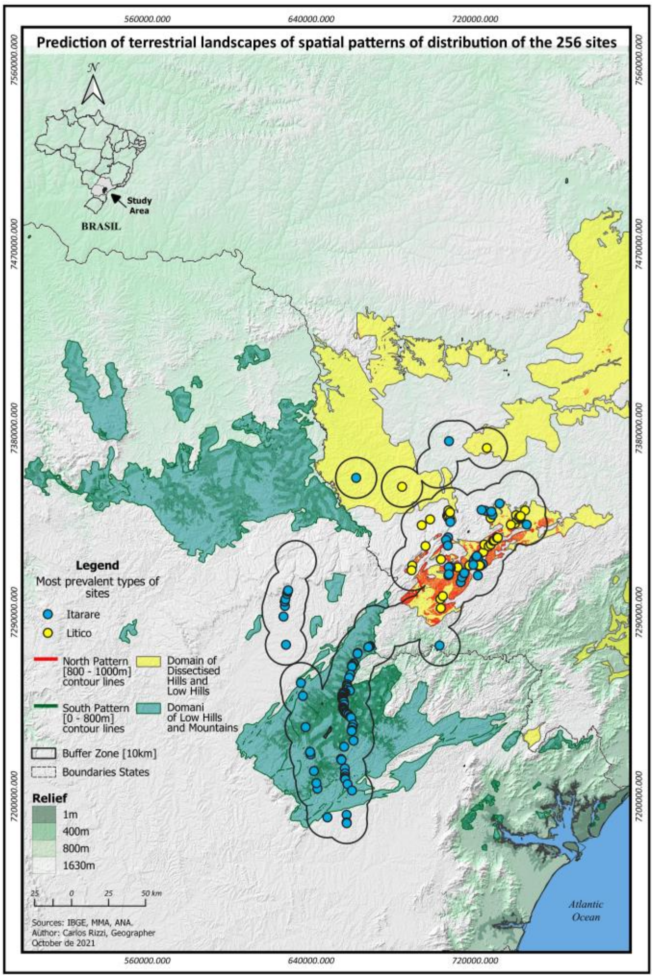

Figure 5 –Prediction of terrestrial landscapes of spatial patterns of distribution of the 256 sites

As a result, we can observe the spatial distribution of the Domains of Dissected Hills and Low Hills and areas of the Hill Dominance and Low Mountains. We can also observe the distribution of altimetric elevations that sought to differentiate the two spatial patterns observed in the IDW modeling: altimetric elevations up to 100m in altitude from 2,000 to 3,000m from the nearest streams and rivers (in red) and altimetric elevations between 800 and 1,000m of altitude, up to 800m from the nearest streams and rivers (in purple).

The 10km radius of influence buffers that the archeological bibliography understands as the limit frontier for mobility in search of fundraising can also be observed. It is noted that there is great geographic correspondence between what is meant by the radius of fundraising and the spatialization of the prediction areas according to the metric of the level curves cut by proximity and distance to the watercourses.

4. Discussion

The proximity or distance to the water courses and the position in the continental relief are pertinent regionalized variables for predicting the location of archaeological sites. Linking the reading of the IDW modeling in Figure 2 with the tabulations of graphs and tables, we can see that, while we observe a pattern in the south that follows a spatial logic of installation of sites in flat places far from rivers, to the north, we have a pattern where sites are associated with high places and close to rivers.

Such a concentration of sites in these two landscape units reinforces the perception of two macro-spatial patterns of distribution of archaeological sites. As can be seen in Figure 5, a synthesis effort was made that sought to associate the altimetry ranges, the proximity-distance relationship with closer rivers, and, as analyzed for the case of the IDW models, with the superposition of the two terrestrial landscapes mentioned where the most archaeological sites are concentrated.

In Figure 5, the northern pattern is highlighted, where the relationship between the variables shows a marked concentration of Lithic-type sites almost exclusively in landscapes whose altitudes are between 800 to 1,000 meters above sea level, close to 800 meters from local rivers and streams. Lithic sites are predominantly concentrated in landscapes of dissected hills and low hills and this spatial relationship is not found in other areas of the observable scale of the map.

For the southern pattern, the combination of variables given by the specificities of their respective modeling denotes the concentration of sites in altimetric elevations up to 100 meters above sea level, 2,000 to 3,000 meters away from any nearest stream. This combination is concentrated in the terrestrial landscapes of low hills and mountains. There is an extensive area to the north of the map with the same environmental characteristics but not archaeological sites.

It is concluded from the spatial analysis that the area in question represents a transition zone of human behavior related to the physical landscape.

According to the observation of altimetry, territorial compartmentalization can mean a form of changes in the relationship with the landscape due to significant changes in the installation of flat places to very high, and the same occurs inversely with regard to water courses, going from long distances to short distances. It is inferred from the data obtained that human groups are remodeling the landscape from an interchange in the area of the Paranapanema River.

We do not know how much time passed before these characteristics were completed. However, human groups change their relationship with the environment and their insertion, which can mean preference and inclusion culturally, or it can be an initiative taken due to territorial conflicts existing between groups.

It is pertinent to consider that the area can be characterized as a fluid and non-restrictive cultural frontier, a place in which a series of natural resources management has been modified by different technological complexes, according to available natural resources and culturally appropriated, regardless of natural characteristics.

The landscape features were not neglected at any time by pre-colonial groups when considering the level of prediction and possibility of obtaining resources, observed by all technological complexes, so that, for archaeology, predictive maps considerably help to obtain targets potential and characteristics of the search for archaeological sites.

Nevertheless, as noted, human groups are dynamic and respond to the environment differently, so that prediction is just a compass and not a deterministic situation that geoprocessing substantially helps to propose new approaches to old border problems between human groups.

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