ISSN: 2447-3359

REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

v. 11, nº 1 (2025)

https://doi.org/10.21680/2447-3359.2025v11n1ID37691

Spatial analysis of correlation between the Human Development Index and agricultural activities in Marajó Island, Pará, Brazil.

Análise espacial de correlação entre o índice de desenvolvimento humano e as atividades agropecuárias na Ilha do Marajó, Pará, Brasil.

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Abstract: The economy of Marajó Island is shaped by activities such as livestock farming—particularly buffalo farming in the island's natural fields—forest extraction, and small-scale agriculture, which have been practiced since colonial times. In light of the region's low Human Development Index (HDI) scores, this study examines the correlation between agricultural activities and HDI across the municipalities of Marajó Island. The methodology involved organizing HDI data and agricultural census information for the centroids of 16 municipalities and applying the Inverse Distance Weighted (IDW) method to spatialize these attributes. Due to the non-normal distribution of the data, Spearman's correlation was employed. The results revealed a moderate positive correlation between buffalo farming and pineapple cultivation with HDI, indicating that these activities, along with tourism, contribute to improvements in human development. In contrast, poultry farming showed a moderate negative correlation, suggesting it may reflect a form of local economic resilience. This study contributes to understanding the relationship between specific agricultural activities and human development in a region that has received limited research attention. By utilizing spatial analysis, it provides new insights into the interplay between agricultural practices and HDI, emphasizing the need for locally tailored strategies to foster sustainable development.

Keywords: Spatial analysis; Human Development; Marajó Island.

Resumo: A economia da Ilha do Marajó é influenciada por atividades vinculadas à pecuária, particularmente, a bubalina, cultivada nos campos naturais da Ilha, ao extrativismo nas áreas de floresta e à pequena agricultura desenvolvida desde o período colonial. Nesse contexto, diante das baixas pontuações de IDH, esse estudo analisa a correlação entre atividades agropecuárias e o Índice de Desenvolvimento Humano (IDH) nos municípios da Ilha do Marajó. A metodologia envolveu a organização dos dados de IDH e do censo agropecuário nos centroides dos 16 municípios e a aplicação do método Inverso da Distância Ponderada (IDW) para espacializar os atributos. Como os dados não apresentaram normalidade, foi utilizada a correlação de Spearman. Os resultados mostraram uma correlação moderada e positiva entre a bubalinocultura e a abacaxicultura com o IDH, sugerindo que essas atividades, junto com o turismo, promovem melhorias no desenvolvimento humano. Por outro lado, a criação de galináceos mostrou uma correlação moderada e negativa, indicando uma forma de resiliência local. O estudo explora a correlação entre atividades agropecuárias específicas e o desenvolvimento humano em uma região pouco estudada, utilizando análise espacial para fornecer novos percepções sobre práticas agropecuárias e IDH, destacando a importância de estratégias locais para o desenvolvimento sustentável.

Palavras-chave: Análise espacial; Desenvolvimento Humano; Ilha do Marajó.

Recebido: 16/09/2024; Aceito: 09/01/2025; Publicado: 29/01/2025.

1. Introduction

The Amazon estuary results from the convergence of two major river basins: the Amazon River and the Tocantins-Araguaia, both discharging into the Atlantic Ocean. At the confluence of these waters lies Marajó Island, composed of diverse geo-environmental zones that reflect the complexity and diversity of fluvial-marine landscapes, forming the largest fluviomarine island on the planet (HENRIQUES et al., 2022).

The economy of Marajó Island is based on agriculture and livestock, particularly buffalo farming, which represents Brazil's largest buffalo herd, along with agriculture, fishing, and forest extraction, essential for local subsistence (FAPESPA, 2024; NASCIMENTO & BARROS, 2021). These activities, developed since colonial times, have shaped riverside and *quilombola* communities that preserve cultural and economic practices adapted to the region's environmental conditions (COSTA, 2022). Mobility between municipalities is limited by the absence of highways and navigation challenges due to factors such as low water levels at certain times of the year (COSTA, 2021; ARAÚJO et al., 2022).

In this context, the municipalities of Marajó Island maintain lifestyles with low-quality standards, limiting the potential for sustainable economic development (BARBOSA, 2022). In 2010, Marajó municipalities recorded Brazil's lowest Human Development Index (HDI) (ATLAS DO DESENVOLVIMENTO HUMANO NO BRASIL, 2022). Thus, analyzing the correlation between HDI and agricultural activities in Marajó Island is essential to track improvements or degradations in the living conditions of the Marajó population.

Brazil is a global leader in exporting commodities, with increasing competitiveness, export volumes, and product values, leading to a positive balance in the agribusiness international market (SOSSA & DUARTE, 2019). However, regions distant from commodity production and trade centers, such as the municipalities in Marajó Island, do not necessarily benefit from this economic profile. Historically, the economy of Marajó Island has promoted the development of latifundia, the marginalization of local communities, and the exploitation of natural resources to generate wealth, without enhancing the living conditions of traditional populations (CARVALHO et al., 2019; SILVA et al., 2019).

Thus, spatial analysis emerges as an effective method to more precisely explain phenomena related to agricultural activities and HDI, allowing a detailed representation of environmental and anthropic phenomena. This facilitates understanding the interactions that occur in land occupation and transformation processes (MARQUES, 2024). When applied to spatial data at the municipal level, this approach reveals direct relationships between changes in HDI and the agricultural activities carried out in the region.

This study aimed to analyze the correlation between specific agricultural activities in the municipalities of Marajó Island and HDI through spatial analysis.

2. Background

2.1 Human Development Index (HDI)

The HDI evaluates quality of life by considering health, education, and income, contrasting with the Gross Domestic Product (GDP), which focuses on economic aspects (PNUD, 2024; IBGE, 2023; ATLAS BRASIL, 2022). In Brazil, the HDI reveals disparities, such as in Pará state, which in 2021 ranked 24th nationally, with an HDI of 0.645 (ATLAS DO DESENVOLVIMENTO HUMANO NO BRASIL, 2022). In 2010, Melgaço recorded the lowest HDI in the country, 0.418, reflecting limitations in income, education, and health (ANDRADE, 2019; PNUD, 2024). Municipal data from 2010 continue to serve as a reference point pending updates from the 2022 Census (ATLAS BRASIL, 2022; PNUD, 2024). In Marajó Island, most municipalities have low or very low HDI scores, with five municipalities below 0.499.

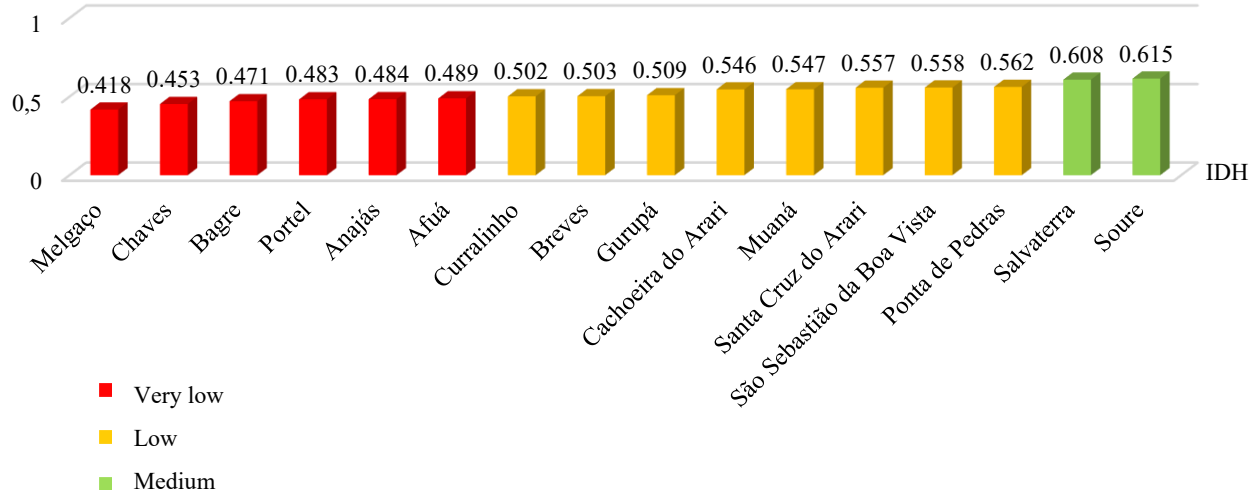

Figure 1 – HDI of the municipalities of Marajó.
Source: IBGE (2010).

2.2 Land Use and Land Cover in Marajó Island

According to data from MapBiomas Collection 9 (MAPBIOMAS BRASIL, 2024), it is possible to analyze changes in the various land use classes in Marajó Island. The 2023 analysis details the distribution of diverse land use categories expressed in square kilometers, providing spatial dimensions of land use. The classified data on land use and land cover are presented in more detailed spatial dimensions (Figure 2).

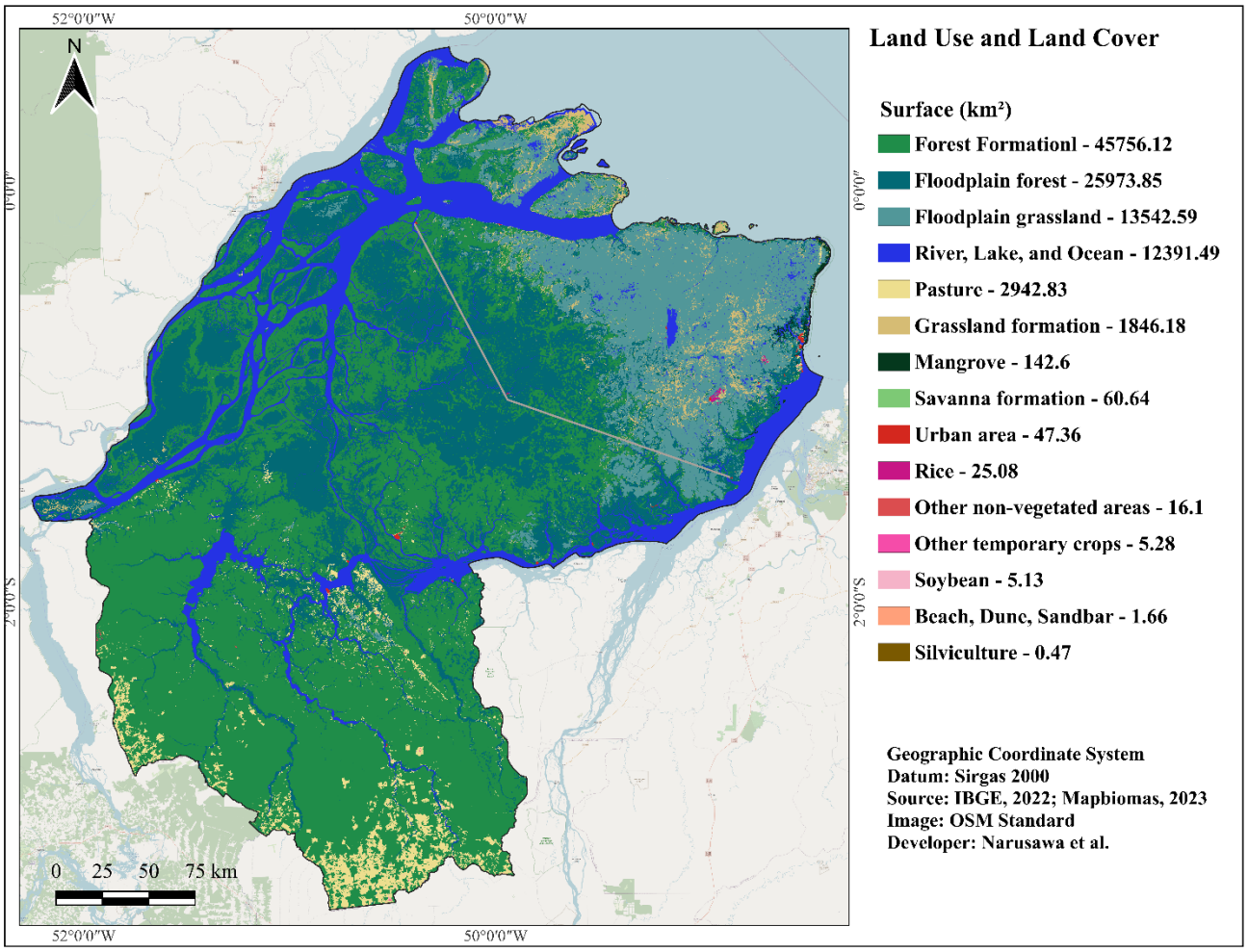

Figure 2 – Land Use and Land Cover of Marajó Island.
Source: Authors (2024).

Marajó Island is predominantly covered by forest formations, occupying 45,756.12 km² (44.53%), characterized by dense forests and rich biodiversity (SILVA et al., 2021). Floodplain forests cover 25,973.85 km² (25.28%), and floodplain grassland accounts for 13,542.59 km² (13.18%), which regulate water flow and contribute to ecological balance (FAROOQI et al., 2024).

Rivers, lakes, and ocean areas span 12,391.49 km² (12.06%), influencing the local climate (KALFAS et al., 2024; GAROFOLO & RODRIGUEZ, 2022). Pastures total 2,942.83 km² (2.86%), holding economic relevance (IBGE, 2024). Grassland formations occupy 1,846.18 km² (1.80%), often associated with forest degradation (KOHLER et al., 2021; MAPBIOMAS, 2023).

Mangroves cover 142.60 km² (0.14%), crucial for coastal protection, while savanna formations span 60.64 km² (0.06%) (MMA, 2021). Urbanized areas comprise only 47.36 km² (0.05%) (DA SILVA et al., 2021). Rice cultivation covers 25.08 km² (0.02%), largely focused on artisanal and subsistence farming (SILVA & CRUZ, 2024).

Other areas include beaches, dunes, and sandbars (1.66 km²), as well as silviculture (0.47 km²). Temporary crops and soybean cultivation remain minimal (5.28 km² and 5.13 km², respectively), reflecting environmental limitations (OPPLERT, 2023; ROCHA et al., 2023). While natural formations dominate the island, agriculture and livestock, although occupying smaller areas, hold significant socioeconomic importance (ROCHA et al., 2023).

3. Methodology

3.1 Study Area Characterization

The research focuses on Marajó Island, located in northern Pará state, consisting of approximately three thousand islands in the world's largest fluviomarine archipelago. As part of an Environmental Protection Area (EPA), the region plays a strategic role in Brazil's ecological scenario and is notable for ecotourism and environmental conservation initiatives (ARAÚJO et al., 2022). "Marajó," meaning "taken from the sea" or "sea shield" in the Tupi language (GALLO, 1997), comprises 16 municipalities with a humid tropical climate (Af and Am) and annual precipitation between 2,366 mm and 4,000 mm (CLIMATEMPO, 2023). The soils range from deep and chemically specific Latosols in upland areas to hydromorphic Plinthosols common in flooded areas (MARQUES, 2024; EMBRAPA, 2016).

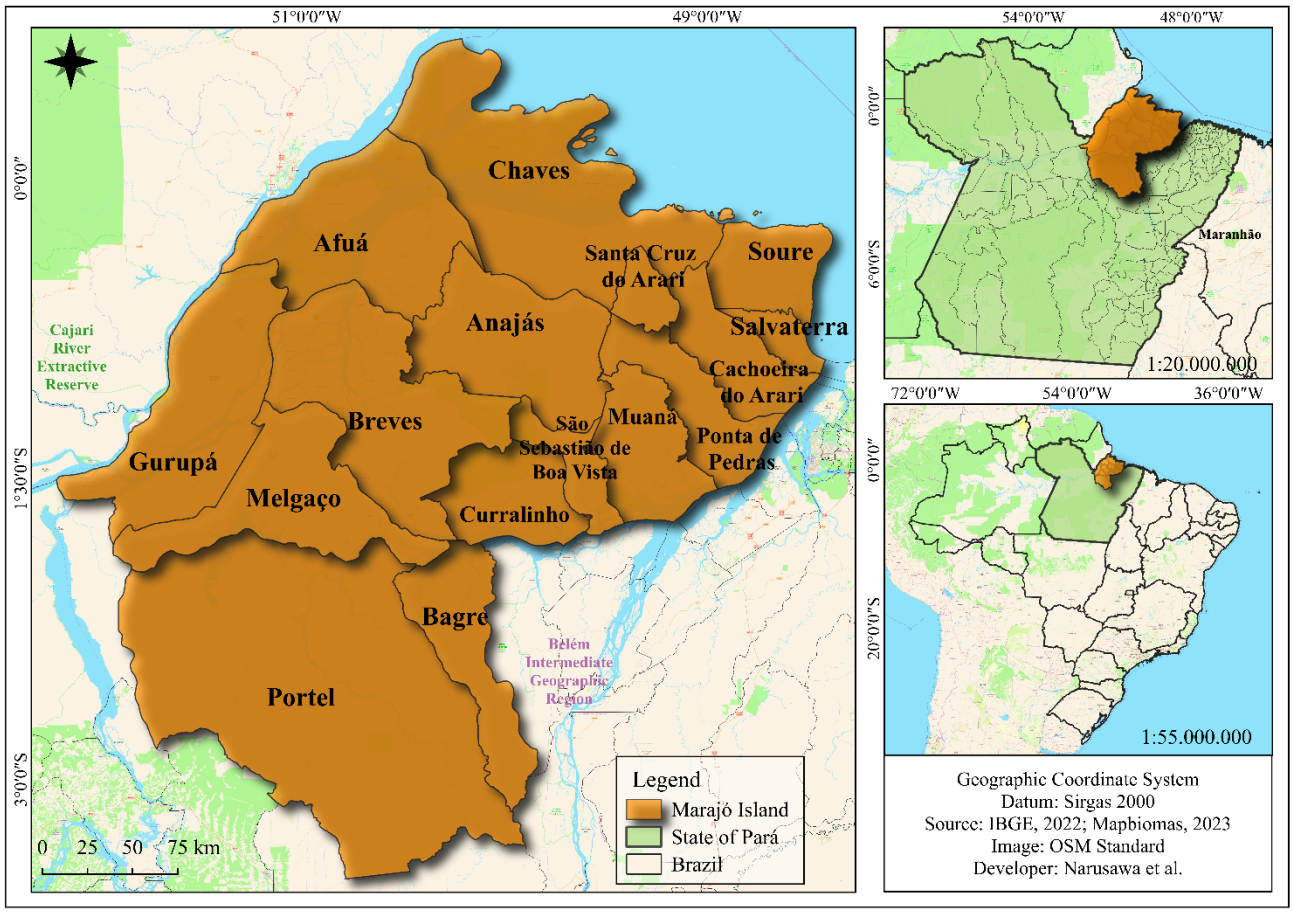

Figure 3 – Study area.
Source: Authors (2024).

3.2 Data Collection

To obtain data on the agricultural characteristics of municipalities and HDI, census data were collected from the IBGE database. Following an analysis of the agricultural census (IBGE, 2017), key agricultural activities were identified that correlate with HDI, including pineapple production value (in BRL), buffalo population, and poultry population. Additionally, cartographic data from IBGE (2023) in *shapefile* format were acquired, from which the municipalities of Marajó Island were extracted. A *shapefile* of points was then created at the *centroids* of the municipalities, serving as

reference points for spatialization. The study attributes were tabulated in the *centroid shapefile* for subsequent spatialization.

3.3 Spatialization of Attributes

The spatialization of attributes was performed using the Inverse Distance Weighted (IDW) interpolation method, with a distance coefficient (P) of 2. In this method, the value at the estimated point is calculated as the weighted average of neighboring samples, with weights defined by the inverse of the distance between samples and the point being estimated (YAMAMOTO, 2020). The mathematical formula is given by the equation:

$$Z = \frac{\sum_{i=1}^{n} \frac{Zi}{hij^{p}}}{\sum_{i=1}^{n} \frac{1}{hij^{p}}} \quad (1)$$

Where:
Z = estimated values,
Zi = known values,
i = known point,
j = point to be interpolated,
hij = distance between known and estimated values,
p = weighting exponent,
n = number of samples.

3.4 Correlation Analysis

After creating maps spatializing the studied attributes, the raster data were vectorized for pixel-by-pixel correlation analysis. This process aligns the information from each map based on a common factor, the *centroid* of the geographic coordinate of each pixel, enabling linear correlation analysis.

Preliminary data analyses were conducted to select the most appropriate test. This procedure consists of determining whether the means and standard deviations are the most appropriate references of central tendency to represent each group of the data. These included checking data normality using the Kolmogorov-Smirnov test, detecting outliers through boxplot analysis, and assessing homoscedasticity via scatterplots of residuals from linear models. As the assumptions of normality of the data were not fulfilled, Spearman's nonparametric correlation test was used to verify the factors of growth or decrease of the variables with the HDI. The mathematical formula is given by the equation:

$$\rho = 1 - \frac{6 \sum_{i=1}^{j} di^{2}}{n^{3} - n} \quad (2)$$

Where:
ρ = Spearman's correlation coefficient,
di = xi-yi the difference of positions of the X and Y scores,
n = number of observations.

Using Spearman's correlation coefficients, Table 1 was employed to interpret the strength of the relationship between variables, following a scale adapted from Callegari-Jacques (2021). Additionally, correlation matrices and scatterplots were created to visualize these relationships.

Table 1 – Interpretation of Spearman's Correlation Coefficients.

Value of ρ (+ or -)	Degree of correlation
0.00 ~ 0.19	Very weak correlation

0.20 ~ 0.39	Weak correlation
0.40 ~ 0.69	Moderate correlation
0.70 ~ 0.89	Strong correlation
0.90 ~ 1.00	Very strong correlation

Source: Adapted from Callegari-Jacques (2021).

3.5 Software utilized

Data tabulation was performed using Microsoft Office 2016. Map *layouts* were created using QGIS 3.22.9, a free and open-source software. The *centroid shapefile* for Marajó municipalities was created using QGIS 3.22.9 *centroid* tool. IDW maps were generated using the *Raster interpolation* tool in QGIS 3.22.9, and spatial variability maps were vectorized with the raster-to-points tool. For the vectorization of the maps of spatial variability of the attributes, the following tool was used: *raster pixel to points* from QGIS 3.22.9.

To conduct the Kolmogorov-Smirnov normality test, an assessment of data homoscedasticity was performed by constructing scatter plots of the residuals from linear models generated pairwise. Outliers were verified through the creation of boxplots. Additionally, Spearman's nonparametric correlation test, along with scatter plots and correlation matrices, were constructed. The R programming language version 4.2.1 was utilized, alongside the R Studio interface and the dgof, ggplot2, and corrplot packages.

4. Results and discussion

4.1 Descriptive analysis of data

Figure 4 illustrates the results of the Kolmogorov-Smirnov normality test, the median (Q2), the interquartile range (Q1 and Q3), and the boxplot for the spatialized attributes of Human Development Index (HDI), the production value of pineapples (BRL), and the populations of buffalo and poultry in Marajó Island. The non-normal distribution of the data, along with the presence of outliers, indicates high spatial variability (YAMAMOTO, 2020). This demonstrates a region with diverse agricultural activities and varying HDI values. The geographic diversity of Marajó Island, including equatorial forests, transitional areas, and natural fields influenced by both fluvial and marine environments, possibly contributes to this variability (IPEA, 2020). These diverse geographic conditions foster distinct agricultural practices, intensifying land use, such as the natural fields employed for cattle and buffalo farming, supporting the observed spatial variability.

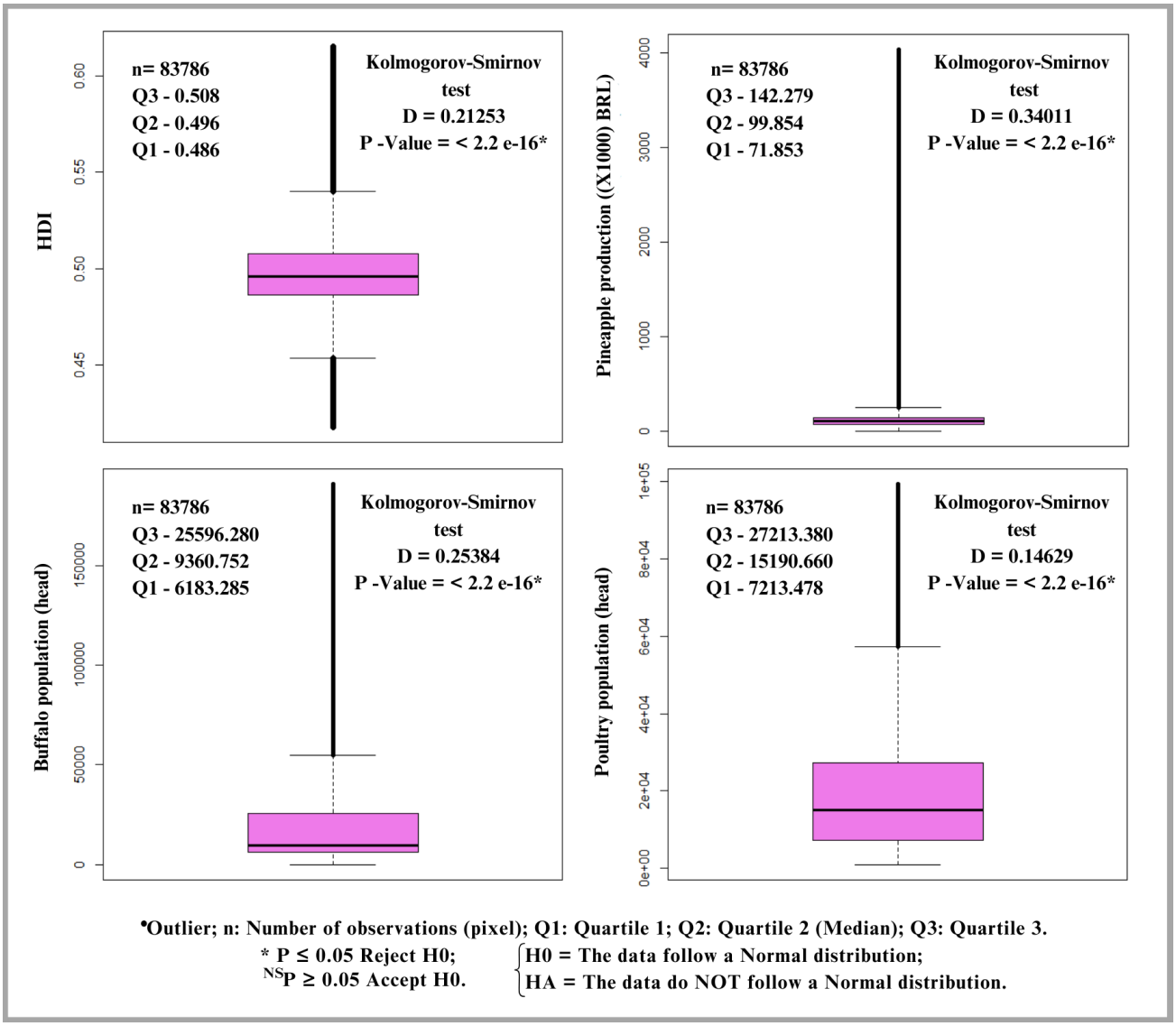

Figure 4 – Descriptive Analysis of HDI and Agricultural Attributes in Marajó Island.
Source: Authors (2024).

Geographic diversity also impacts accessibility, resulting in lower HDI scores for municipalities located in the inland region of the archipelago. The spatial distribution of HDI in Marajó Island (Figure 5) reveals higher scores in the northeastern region, with Soure and Salvaterra municipalities achieving the highest index. Conversely, HDI values decrease toward the west and south, with Melgaço and Chaves reporting the lowest index. This pattern is likely linked to tourism activities, as Soure and Salvaterra function as key entry points for visitors to Marajó Island. The island is situated approximately 87 kilometers from Belém, the state capital, and is accessible via the Camará port in Salvaterra (MEGUIS, 2018).

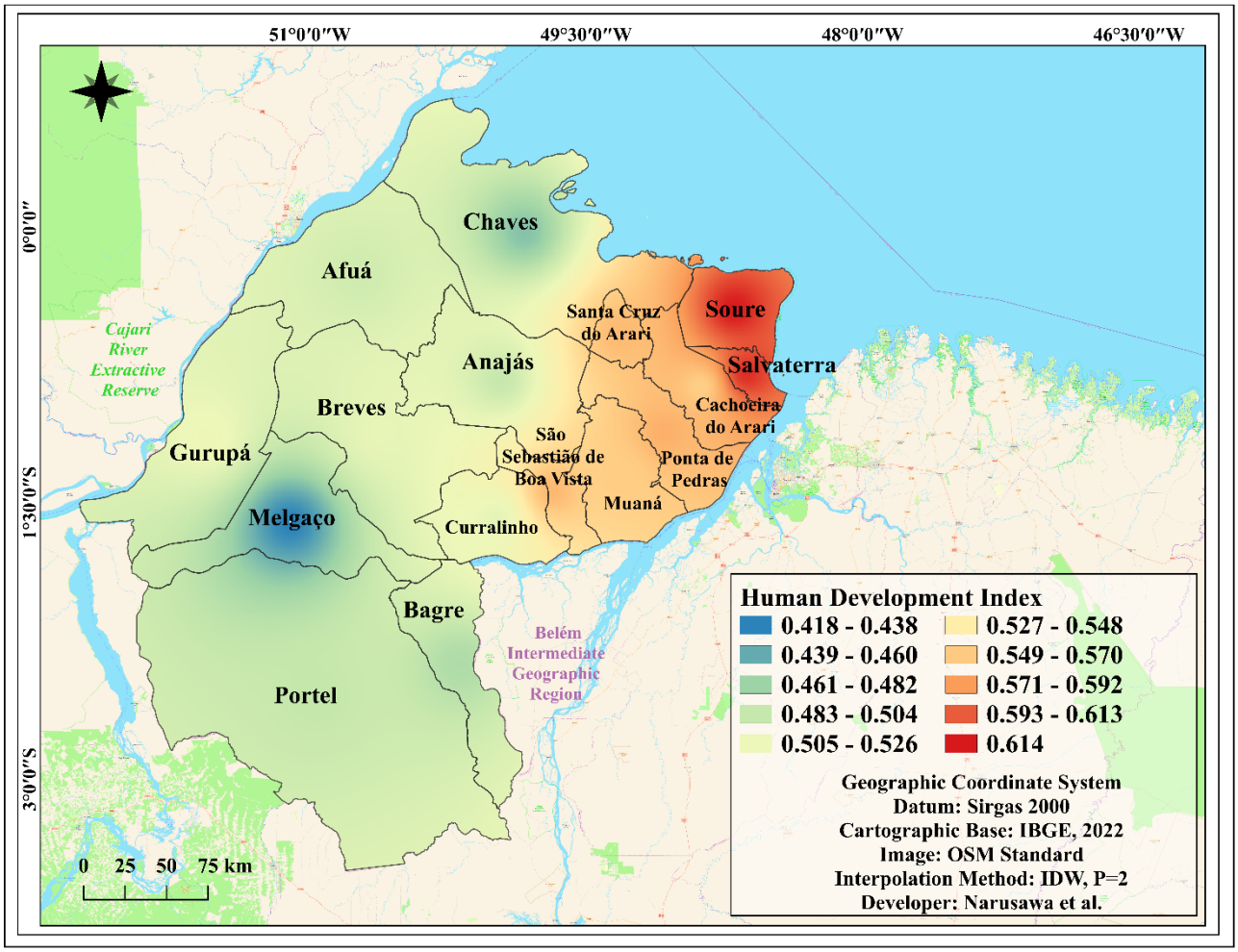

Figure 5 – Spatialization of HDI in Marajó Island.
Source: Authors (2024).

The competitive nature of the tourism industry significantly contributes to the economic and urban growth of the region. State initiatives, such as Pará's strategic tourism plan, have prioritized tourism and gastronomy as vital economic sectors (SETUR, 2020). In this context, the cities of Soure and Salvaterra stand out as having the most developed infrastructure in terms of transportation, public services, and accessibility. These features support rural tourism on local farms, the commercialization of products derived from cattle and buffalo herds, and the cultivation of small- to medium-scale regional fruit plantations. Additionally, the region is renowned for its scenic local beaches (SETUR, 2020).

4.2 Correlation Analysis between agricultural activities and HDI

Figure 6 presents the Spearman correlation matrix illustrating relationships between HDI and the studied attributes. The analysis reveals a moderate positive correlation between the Human Development Index (HDI) and two economic factors: the size of buffalo populations and the monetary value of pineapple production (BRL). The findings indicate that buffalo farming and pineapple cultivation are linked to enhancements in human development indicators, likely driven by the income generation and economic benefits these activities provide to local communities.

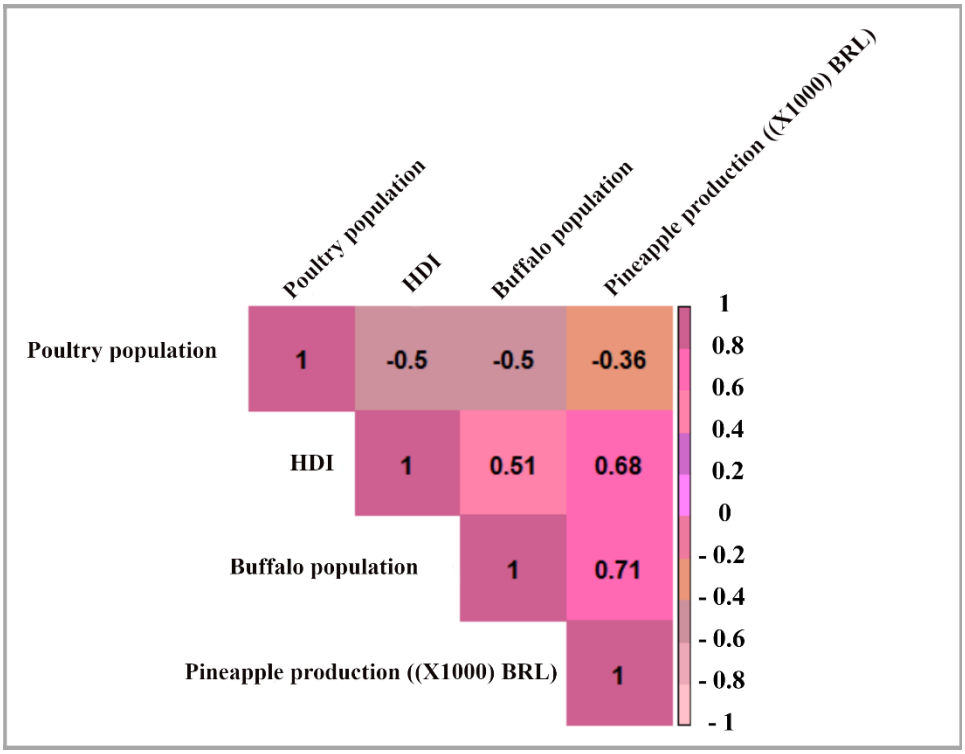

Figure 6 – Correlation matrix between agricultural activities and HDI.
Source: Authors (2024).

Conversely, a moderate negative correlation was observed between HDI and poultry populations, potentially reflecting the nature of poultry production as a subsistence-oriented activity prevalent in less developed areas. These correlations prompted a more detailed analysis of the distribution of attributes in relation to the Human Development Index (HDI), taking into account potential factors contributing to the growth or decline of each variable. To this end, local dynamics that may influence these relationships were examined, including socioeconomic conditions, public policies, and regional production practices. This approach provides insight into how various economic activities and their associated impacts influence human development levels, either positively or negatively. It also offers a foundation for developing strategies aimed at fostering sustainable growth and enhancing the quality of life for the affected populations (SILVA & CRUZ, 2024).

4.3 Correlation Analysis (Buffalo Farming and HDI)

Figure 7 depicts spatial maps for buffalo populations (A) and HDI (B), alongside a scatterplot (C) showing the Spearman correlation coefficient, p-value, and linear trend model (in blue). A moderate, positive, and statistically significant correlation is observed between the buffalo population and the Human Development Index (HDI). The increase in HDI may be associated with improvements in living conditions facilitated by buffalo farming in the region. A key factor contributing to this activity's impact is the species' hardiness, which enables simple and low-cost management practices (SANTOS, 2020). Buffalo farming produces a variety of goods, including meat, milk, cheese, and leather, and is also utilized for cargo transportation. The presence of buffalo also attracts tourists interested in encountering the animal, thereby contributing to the growth of local tourism. Among the products, buffalo cheese is particularly noteworthy. Between 2007 and 2014, cheese production experienced significant growth, driven by the adoption of advanced technologies and genetic improvements in buffalo herds. During this period, prices remained stable and profitable, providing substantial benefits to the sector (AMORIM, 2019).

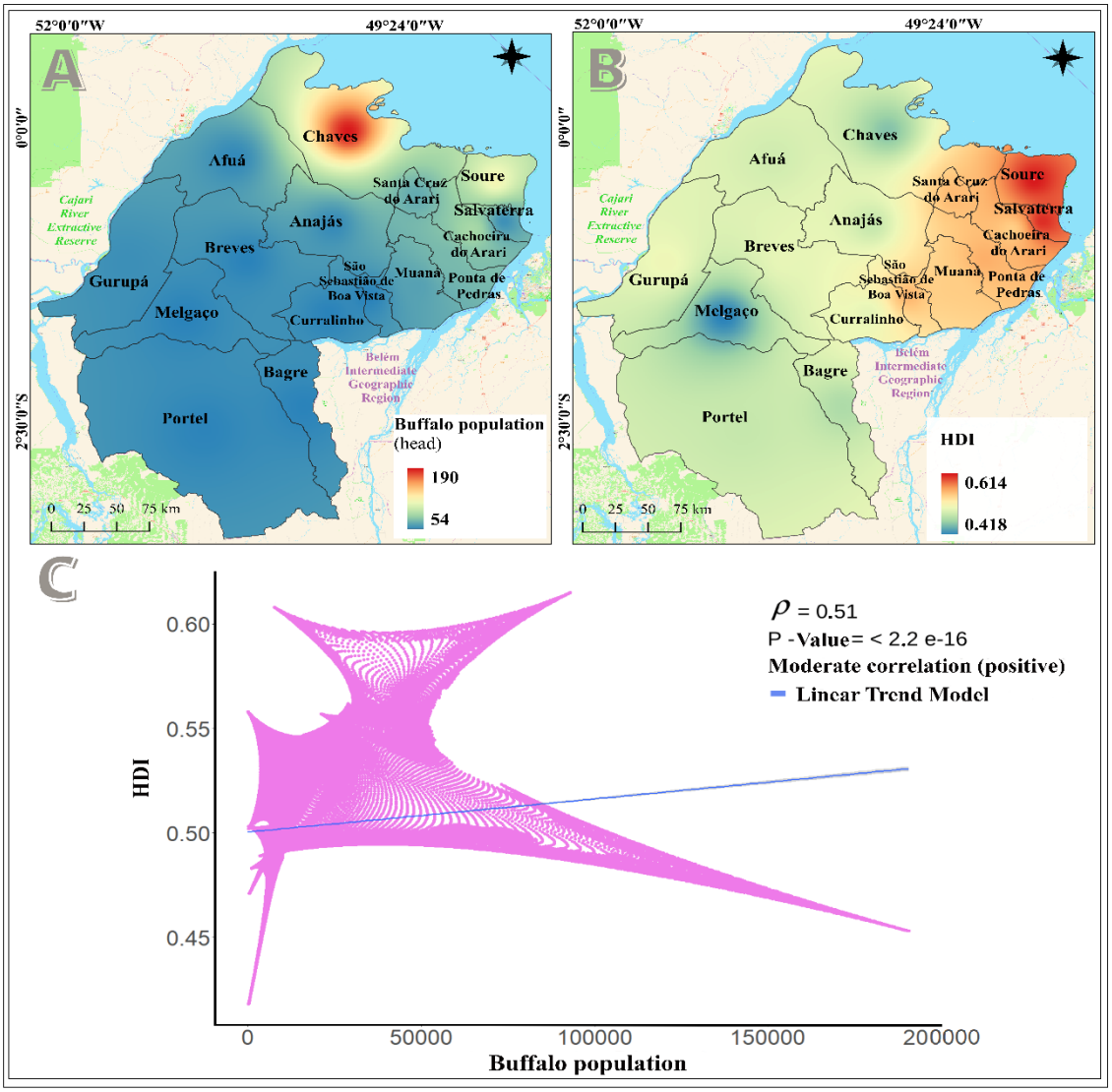

Figure 7 – Spatial Analysis of Buffalo Populations (A), HDI (B), and Scatterplot (C). Source: Authors (2024).

Despite the positive contributions of buffalo farming to the archipelago, certain areas, such as Chaves, exhibit a disparity. Although these regions maintain large herds, they rank low on the Human Development Index (HDI), reflecting a misalignment with expected outcomes. This discrepancy may be attributed to the geographical characteristics previously discussed. Chaves encompasses a vast and remote territorial area, where river transport is the sole means of access to urban commercial centers. This logistical challenge significantly hinders the distribution of its products, particularly buffalo-derived goods such as milk and its derivatives, which are highly perishable (CAVALI & PEREIRA, 2023; SANTOS, 2020). Another potential factor is the conflict between preserving natural ecosystems and meeting the demands of local socioeconomic development. This imbalance between the exploitation of natural resources and the social benefits returned to the local population may contribute to the region's low Human Development Index (ALHO, 2019).

4.4 Correlation Analysis (Pineapple and HDI)

Figure 8 shows the spatialization maps of the pineapple production value attributes (BRL) (A) and the HDI (B), the scatter plot (C), the Spearman coefficient, along with its p-value and the linear trend model of the data (in blue). A

moderate, positive, and statistically significant correlation exists between the value of pineapple production (BRL) and the Human Development Index (HDI).

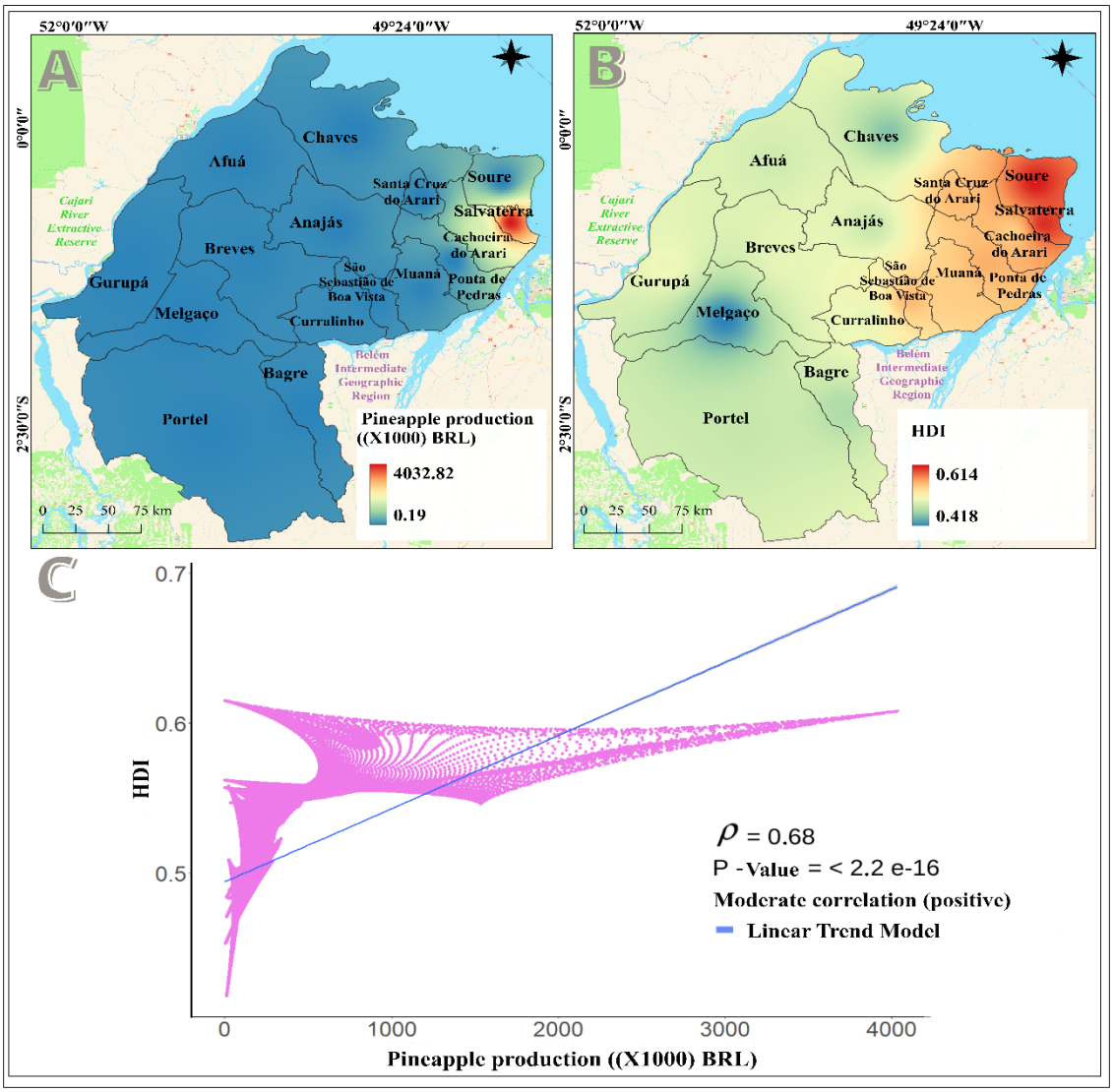

Figure 8 – Spatialization of attributes: pineapple production value (BRL) (A), HDI (B) and scatter plot (C). Source: Authors (2024).

Pineapple is a tropical fruit that is extensively produced and consumed globally, valued for its superior qualitative characteristics and high nutritional content (EMBRAPA, 2022). These attributes contribute to pineapple's significant socioeconomic value, justifying its prominence in cultivation and consumption across numerous countries. According to the 2017 agricultural census, pineapple is the primary crop in the municipalities of Salvaterra and Cachoeira do Arari, serving as a potential factor contributing to the rise in Human Development Index (HDI) in this region of the archipelago. Leão and Steward (2022) highlight that pineapple plantations occupy the largest area in Salvaterra and are solely intended for commercial purposes, not for personal consumption. This contributes to income generation for rural producers and indirectly benefits the region, as it is a highly sought-after fruit among tourists and in major urban centers such as Belém, the primary destination for the fruit (VIANA et al., 2022; NÓBREGA & SANTOS, 2022).

One potential avenue for significant improvement in pineapple cultivation in Marajó Island, which may indirectly contribute to an increase in HDI, is the direct marketing of the product to trade and distribution centers. Furthermore, the

development of social organization through the establishment of associations and cooperatives, which are currently lacking, is crucial. By eliminating the role of intermediaries, this approach would enhance profitability for producing localities, leading to increased income for the municipalities of Marajó Island and, subsequently, a further elevation in the HDI.

4.5 Correlation Analysis (Poultry and HDI)

Figure 9 shows the spatialization maps of the effective attributes of poultry (A) and the HDI (B), the scatter plot (C), the Spearman coefficient, along with its p-value and the linear trend model of the data (in blue). A moderate, negative, and statistically significant correlation is observed between the poultry herd and the Human Development Index (HDI).

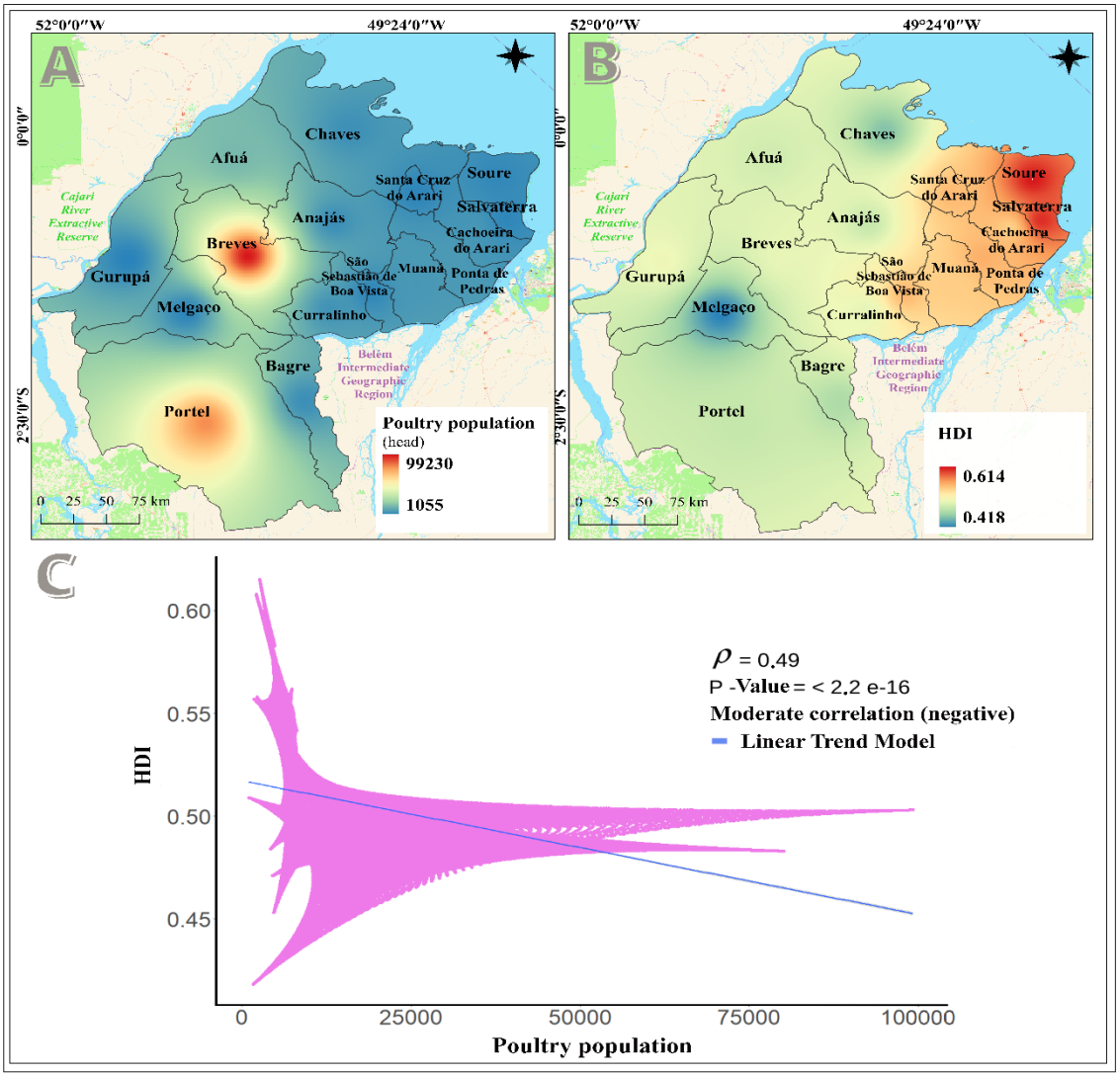

Figure 9 – Spatialization of effective attributes of poultry (A), HDI (B) and scatter plot (C). Source: Authors (2024).

Brazil leads the global exports of chicken meat, standing out for its productive efficiency, competitiveness and compliance with sanitary standards, consolidating its importance in the international market (ABPA, 2024; NUNES et al., 2021).However, in the context of Marajó Island, poultry farming appears to be primarily oriented toward subsistence. The island of Marajó is characterized by extensive municipalities, such as Chaves and Melgaço, where infrastructure—

including roads, bridges, and ports—is either insufficient or entirely lacking. These deficiencies hinder the local economy and urban development, contributing to lower HDI. However, subsistence poultry farming, typically conducted in backyards, rural communities, or the outskirts of larger towns, operates extensively with low productivity. Despite these limitations, it serves as an accessible source of high-quality animal protein and functions as living capital, offering rapid conversion to cash when needed (PEDROSA et al., 2019; FEITOSA JÚNIOR, 2022). This culturally ingrained dietary habit in the region may represent a form of resilience, which could explain its inverse correlation with the HDI.

The implementation of public policies, such as the Family Poultry Program (FPP) developed by the Globoaves Institute (2024), currently active in states like Paraná, Alagoas, Mato Grosso, Rio Grande do Sul, and Rondônia, as well as in countries across Africa and South America, could represent a viable solution for regions like Marajó Island. An example of this is the FPP initiative in Santana do Ipanema, Alagoas, established through a partnership between the municipal government and the State University of Alagoas. This program selected groups of rural producers interested in raising free-range chickens, with the municipality guaranteeing the purchase of all production for inclusion in the Food Acquisition Program (FAP) to supply school meals (LIMA, 2020). Initiatives like this have the potential to transform the poultry farming landscape in the Marajó region and foster a positive correlation with the HDI in the future.

4. Conclusion

The study revealed that agricultural activities, including buffalo farming and pineapple cultivation, are positively correlated with an increase in the Human Development Index (HDI) in Marajó Island. These findings suggest that such practices can play a significant role in enhancing local living conditions. Tourism also emerges as a significant contributor to this developmental progress. Conversely, chicken farming demonstrated a negative correlation with HDI, which may indicate a form of economic resilience among Marajó Island population, particularly in regions with limited infrastructure. These results suggest that promoting buffalo farming, pineapple cultivation, and tourism can serve as effective strategies for fostering human development in the region. This underscores the importance of localized approaches centered on sustainable development.

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