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A GIS-Based Study of the Distribution of Settlements in Roman Britain in Relation to Environmental Factors

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Abstract. This study utilizes Geographic Information Systems (GIS) technology to conduct an analysis of the relationship between the spatial distribution of settlements during the Roman Britain period (43-410 AD) and environmental factors. This study employs the ArcGIS software to process archaeological data and integrate it with natural geographic information. A variety of spatial analysis techniques were utilized to explore the impact of multiple social and natural factors on the distribution of settlements. The research findings indicate that the majority of settlements are concentrated in the southern and central eastern regions of the British Isles, particularly in plain areas near water sources. Nucleated settlements in Roman Britain held significant economic and cultural status. There exists a strong correlation between the economic and cultural activities at these archaeological sites. Furthermore, the distribution of archaeological sites is directly associated with local ecosystem and hydrological features. A multitude of environmental factors collectively determine the distribution characteristics of archaeological sites.

Keywords: Roman Britain; Settlement Distribution; GIS; Environmental Factors; Spatial Analysis.

1. Introduction

Roman Britain (43-410 AD.) was a pivotal period in British history, which witnessed significant social and economic changes. For example, the construction of Roman roads, the planning of towns and cities, and the application of agricultural techniques greatly facilitated interregional trade and cultural exchange. According to Cleary and Simon Esmonde, the embrace of social and cultural norms inspired by Roman models has left an unmistakable imprint on the archaeological landscape [1]. In this period of time, significant changes have taken place in the distribution of settlements due to the use and transformation of the environment. Understanding the distribution of settlements and their relationship to the environment during this period is important for reconstructing the economic and social structure of ancient societies. For example, environment can have an impact on the urban experience, as the ways in which water bodies such as rivers, lakes, and wetlands were integrated into the urban fabric played a significant role in shaping the daily lives of inhabitants [2].

In contemporary times, Geographic Information Systems (GIS) technology has reached a stage of relative maturity and continuous enhancement. The extensive adoption of GIS applications within the field of archeology can be attributed to their robust capabilities in managing, referencing, processing, and particularly visualizing geospatial data [3]. There has been much work on applying GIS to archaeological data management [4, 5]. However, there is a relatively small proportion of studies that integrate archaeological data and utilize GIS for spatial analysis. In fact, GIS can play an important role in studying the relationship between the distribution of ancient settlements and environmental factors. Utilizing GIS benefits revealing how the environment influences the choice and layout of settlements. The Nile Delta, as examined in the study by Zhao et al. (2020), is a good example of how Holocene climate patterns influenced the development of early Egyptian agriculture, with GIS playing a pivotal role in mapping and analyzing the spatial distribution of archaeological evidence [6].

In this paper, we take the advantage of GIS technology and focus on the spatial distribution of settlements in Roman Britain. Based on spatial analysis, we discussed the relationship between the selection of settlements and social and natural factors.

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2. Data Collection

Two datasets are used in our experiments to examine the relationship between the distribution of settlements and natural environmental factors.

1) The Rural Settlement of Roman Britain dataset [7]: This dataset integrates archaeological findings and reports on archaeological excavations since 1990. This open source dataset is available as CSV files, which include site-specific coordinates and statistics on the artefacts excavated at each site.

2) Various types of natural environmental data for the United Kingdom: We have collected and integrated several kinds of nature-related data for of United Kingdom, such as the hydrogeological map of the UK and rivers in Great Britain [8], [9]. All of the data is free and open sourced which is available as ESRI Shapefiles or CSV files.

3. Method

3.1. Data Preprocessing

CSV files cannot be used directly in GIS software, so the acquired data need to be converted into a format compatible with GIS platform, aligned with the correct coordinate system, and have their Attribute connections established between different files before they can be utilized for research. In this report, we employ ArcGIS as the platform for GIS data processing and analysis for a comprehensive evaluation of spatial data related to our interested area. ArcGIS is capable of Processing large amounts of geographic data and provides a rich set of spatial analysis tools.

3.1.1. Data Input and Format Conversion

In ArcGIS, CSV files cannot be directly displayed as point data on the map, so we convert the CSV file containing the Rural Settlement of Roman Britain into Shapefile files by means of selecting longitude and latitude in attribute table. In order to ensure the consistency and accuracy of the maps, as well as to ensure that the deformation of the study area is as small as possible, we have standardised the collected data to the Transverse_Mercator projection and used the British_National_Grid projection coordinate system.

3.1.2. Data Cleaning

The organizations providing the data are indicated in detail in our collection of archaeological site data. However, organizational information is missing for a proportion of the sites in the dataset. We chose to exclude this portion of the data in order to ensure the reliability and accuracy of the data. At the same time, for sites where the number of objects excavated is not clearly indicated in the dataset, we consider that no objects were found.

3.1.3. Attribute connections

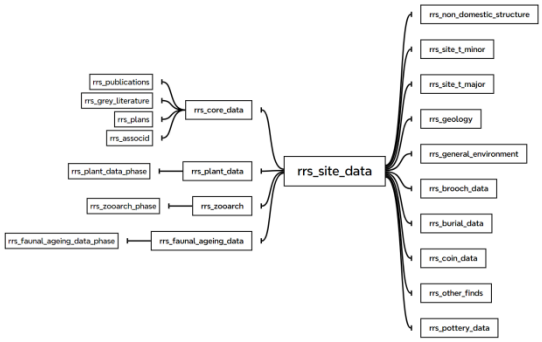

Fig. 1 The dataset comprises primary and ancillary CSV files, outlining archaeological site locations and associated artifact data. The ERD (Fig. 1) depicts the dataset structure, showing how core data interacts with various artifact categories.

The Rural Settlement of Roman Britain dataset is given as multiple CSV files, including the main dataset with specific locations of various archaeological sites, as well as ancillary datasets containing information about the artifacts found at these sites, as shown in Fig. 1. Among all the datasets, only the "rrs_core_data" dataset contains geographic coordinate attributes. In order to make it possible to represent it accurately on the GIS Map and to participate in spatial analyses, We use the "join and relate" function in ArcGIS to connect each type of auxiliary dataset with the "rrs_core_data" dataset containing geographic locations, so as to prepare for the subsequent spatial analysis.

3.2. Spatial analysis

We've collected a total of 3,652 archaeological sites in Roman Britain. These sites include a variety of different land use types, mainly consisting of Rural and Nucleated settlements, but also recording a portion of land use types such as industrial, military, and religious ritual and funerary.

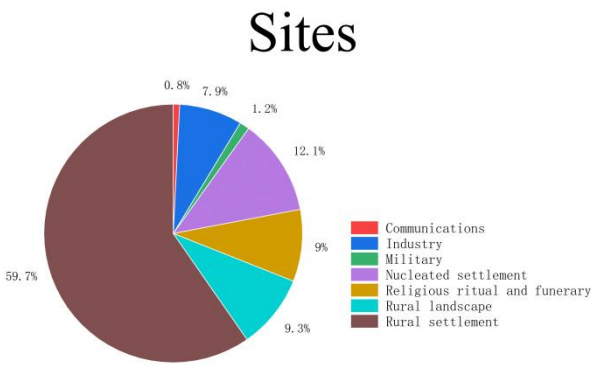

Fig. 2 The diversity of archaeological site types in Roman Britain, ranging from Communications and Military sites to Nucleated and Rural settlements, with counts highlighting the prevalence of each category.

3.2.1. Settlement distribution analysis

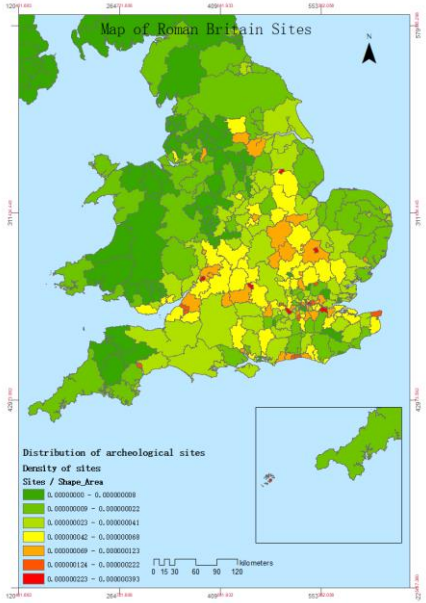

Fig. 3 Distribution of Roman Britain Settlements by Province

In order to explore the spatial distribution patterns of settlement, We have mapped the distribution of Roman Britain settlements. Due to the high total number of sites, the distribution pattern of Sites is not well represented by points. We chose to employ the spatial connectivity function in ArcGIS to

tabulate the number of sites within each province, and use different colors to indicate the density of the number of sites in the region, to more visually represent the overall distribution of sites, as is shown in Fig. 3.

To further enhance the analysis of the spatial distribution of Roman Britain settlements, we have also created a kernel density estimation (KDE) map, depicted in Figure 4. In this map different shades of color represent different levels of settlement density. By combining these techniques, we aim to provide a detailed analysis of settlement patterns and their relationship to both environmental and socio-political factors during the Roman period.

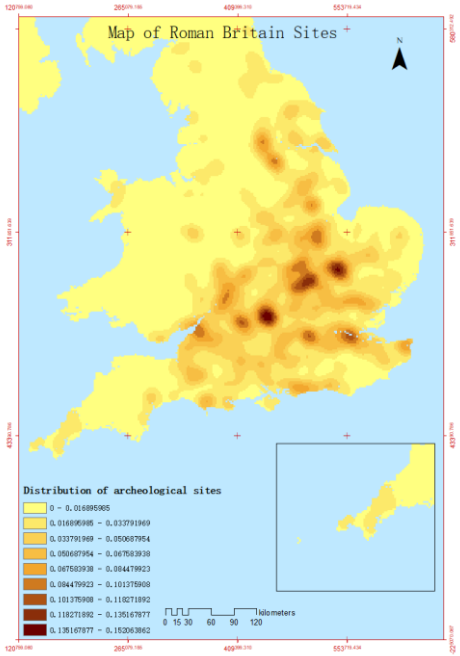

Fig. 4 Kernel density distribution map of Roman Britain Settlements

3.2.2. Economic and Social Interaction Analysis

Previous research has suggested a correlation between pottery production and economic cycles within the Romano-British context [10]. To verify this hypothesis, the present analysis utilizes ArcGIS to examine the spatial distribution of pottery and coins, aiming to analyze the spatial correlation of pottery and coins through GIS, revealing economic activities and social interactions in settlements.

We utilized the spatial autocorrelation analysis tool in ArcGIS, employing the Moran's I index to explore whether coins and pottery exhibit clustered effects or are randomly distributed in space. Subsequently, we joined the coins dataset with the pottery dataset and used ArcGIS's spatial exploratory regression tool to investigate the causal relationship between pottery and coins at each site. We have created a spatial distribution map to examine the relationship between the spatial distribution of coin and pottery finds, specifically to observe if sites with a higher concentration of coins exhibit any spatial correlation with sites that have a higher concentration of pottery.

3.3. Analysis of the impact of the natural environment

The natural environment had a profound effect on ancient settlements. A range of natural conditions such as topography, water, soil and other factors are thought to be directly or indirectly related to the formation and sustainability of settlements [11].

Roman Britain, which is now encompassed within the regions of England and Wales, was predominantly situated in the central and southern parts of the island of Great Britain. The island's rich hydrological and topographical features may influence the distribution of settlements. We utilized ArcMap to investigate the impact of natural environmental factors, specifically soil and rivers, on the selection of settlement locations.

3.3.1. Analysis the impact of ecosystem

We have integrated the Hydrogeology Shapefile data of the United Kingdom (Hydrogeology_625k) with geological and environmental data from the settlement dataset, utilizing spatial analysis tools to construct the geometric relationship between settlements and ecosystem types. Through statistical analysis, we have assessed whether settlements exhibit a preference for specific types of ecosystem. This analysis provides valuable insights into the economic and agricultural strategies of Roman Britain, as well as the role that environmental factors played in the establishment and sustainability of rural communities.

3.3.2. Analysis the impact of Rivers

Utilizing the Shapefile data of rivers in the United Kingdom (OpenRivers), we conducted a proximity analysis to calculate the geometric distance from each settlement to the nearest river, thereby assessing the ease with which settlements can access water sources. We categorized and statistically analyzed the distances of each site from the water source to determine the extent of the influence of water resources on settlement selection.

4. Results

4.1. Composition of sites

Within the corpus of archaeological sites in Roman Britain, settlements constitute a significant proportion, with nucleated settlements exhibiting a notably substantial count (442 out of 2621). This prevalence to a certain extent reflects the impact of the Romans on urban planning in Britain. The prevalence of a substantial number of nucleated settlements may suggest that the Romans advanced a degree of urbanization in Britain, which is consistent with the perspective of (S.T. Loseby) that the Roman Christian mission introduced the concept of towns as centers of power and administration to the country [12].

Table 1. Total number of sites by types

Type of Sites	Total no.	Type of Sites	Total no.
Communications	29	Industry	288
Military	45	Rural landscape	340
Religious ritual and funerary	329	Rural settlement	2179
Nucleated settlement	442		

The higher count of religious ritual and funerary sites compared to Industry sites is also a noteworthy aspect. As depicted in Fig. 5, this category of sites is extensively distributed throughout Roman Britain, encompassing both areas of dense and sparse site concentrations. This distribution underscores the significant role of religious sites during the period of Roman Britain. Previous research has suggested that the Roman Empire was characterized by religious pluralism and tolerance, which contributed to the diversification of religious practices during the period of Roman Britain [13]. The abundance of sites with Roman religious characteristics indicates a vibrant religious life and signifies the profound integration of Roman religious influences in the towns and their surrounding regions of Britain.

4.2. Overall distribution of settlements

Upon examination of the Kernel density distribution map of Roman Britain Settlements, it is observed that the archaeological sites of Roman Britain are predominantly concentrated in the southern and eastern central regions of the British Isles. From the Isles of Scilly in the southwest to the southern

part of the Southern Uplands, the archaeological sites span a large portion of the lowland areas of England and Wales. Regions with a higher density of site distributions are notably concentrated near the Thames River in southern England, with port cities such as Kent, Bristol, and Southampton also exhibiting a significant concentration of archaeological sites. For areas of higher elevation, such as the Cambrian Mis and Pennines, the number of sites distributed is significantly lower.

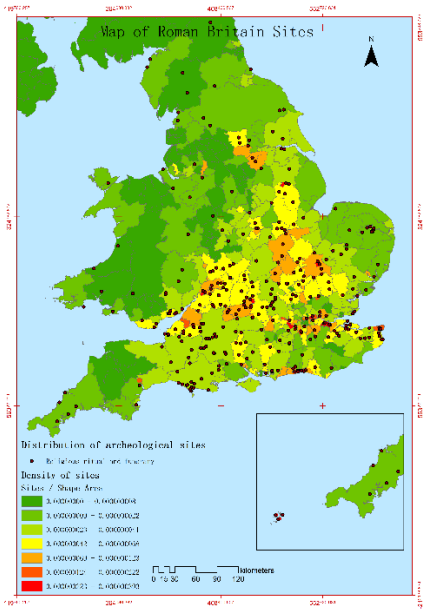

Fig. 5 Distribution of religious ritual and funerary

4.3. Economic and Social Interaction

4.3.1. Autocorrelation

As is depicted in Fig. 6, The spatial autocorrelation analysis conducted on the coins and pottery of Roman Britain sites yielded Critical Values (z-scores) ranging from -1.65 to 1.65, indicating that the global spatial autocorrelation for both coins and pottery is not significant. This suggests that there is no strong evidence of clustering or spatial patterns in the distribution of these artifacts across Roman Britain.

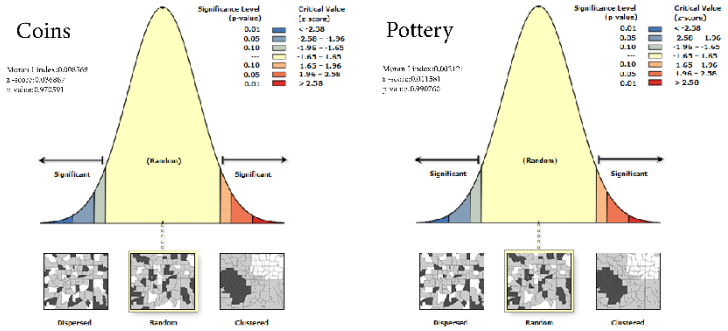

Fig. 6 Spatial autocorrelation scores for Coins and Pottery

A potential explanation is that the increasing of nucleated settlements fulfilled the trade requirements of the inhabitants of Roman Britain, enabling economic activities to be conducted at these locations. When the trade needs of the populace can be met within nucleated settlements, there is a diminished necessity to travel to more distant locales, such as major urban centers, for commercial transactions. Consequently, the widespread presence of such settlements may have reduced reliance on larger urban hubs, thereby influencing the spatial distribution patterns of trade goods, including coins and pottery. This can be inferred from the higher average quantities of coins and pottery shards unearthed at nucleated settlements, as demonstrated in Table 2.

Table 2. Average amount of coins and pottery shards excavated at Nucleated settlements and all sites

Object	Nucleated settlements(avg.)	All sites(avg.)
coins	193.4072398	59.93780822
pottery shards	4650.692308	1744.81589

4.3.2. Relationship between pottery and coins

We conducted an exploratory regression analysis using coins as the explanatory variable and pottery-related variables as candidate explanatory variables. As demonstrated in Table 3,there is a positive correlation between all pottery-related variables and the number of coins, implying that an increase in pottery is associated with a corresponding increase in coins. This aligns with the perspective of (C. J.) [10]. In addition to the most fundamental variables for measuring the quantity of pottery at archaeological sites, such as pottery shards and pottery weight, the number of Samian pottery—a high-quality Roman red painted pottery—also exhibits a high degree of significance in influencing the number of coins. This may be attributed to the fact that Samian, as a luxury good, relies on economic support for its production and circulation, thereby reflecting the economic status and trade level of the archaeological site.

Table 3 The significance, negative, and positive percentages for pottery-related variables found in the archaeological sites.

Variable	% Significant	% Negative	% Positive
pottery shards	100.00	0.00	100.00
SAMIAN	100.00	0.00	100.00
pottery weight	93.75	0.00	100.00
MORTARIUM	56.25	0.00	100.00
AMPHORA	37.50	25.00	75.00

However, when we attempted to construct a model using five pottery-related variables to predict the quantity of coins at archaeological sites, the results were not satisfactory, as demonstrated in Table 4. The optimal model's Adjusted R-squared value is less than 0.5, and the AICc is substantially high, indicating a poor model fit and suggesting that the model lacks statistical significance. We believe this is due to the fact that the number of coins within archaeological sites is not solely influenced by pottery production and trade; a multitude of factors can affect the quantity of coins to varying degrees, including natural resources and mineral wealth. Consequently, a limited number of variables may fail to fully capture the complex factors influencing the distribution of coins. Additionally, the varying contexts of use and preservation practices for pottery and coins can lead to differences in their distribution patterns.

Table 4 Statistical metrics of the regression model, including the Adjusted R-squared (AdjR2), Akaike Information Criterion (AICc), Jarque-Bera test's Koenker statistic (JB K(BP)), Variance Inflation Factor (VIF), significance of the Global Moran's I (SA).

AdjR2	AICc	JB K(BP)	VIF	SA	Model
0.08	53995.57	0.00	0.58	2.00	0.52

4.4. The impact of ecosystem

We selected 467 archaeological sites with recorded specific environmental information and combined them with Hydrogeology data for analysis. As depicted in Fig. 7, the distribution pattern of these sites closely resembles that of all sites, thereby allowing us to infer that the environmental characteristics of these sites are representative of the environmental context of the entire archaeological assemblage to a certain extent.

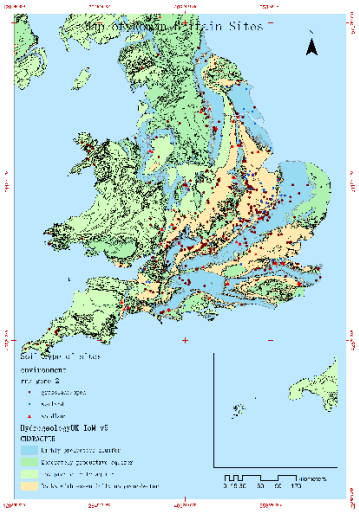

Fig. 7 Ecosystem types and hydrogeology of Roman Britain sites

In the studied archaeological sites, grassland ecosystems constitute a significant majority, accounting for 70.4% of the total, while wetland ecosystems represent 17.1%, slightly exceeding the 12.4% attributed to woodland ecosystems. Food production is one of the most critical factors in the selection of settlement sites, as sufficient food is fundamental to sustaining the survival and social development of the settlement's population. Grasslands, being the most prevalent ecosystem type, typically possess fertile soils and relatively open topography that provide ample sunlight conditions for crop growth, thereby making them more suitable for agricultural activities compared to the other two types. Concurrently, grazing animals such as sheep and cattle are considered to have been significant livestock during the Roman Britain period [14]. Grasslands provided these animals with abundant forage resources, which in turn would have fostered the utilization of grassland ecosystems.

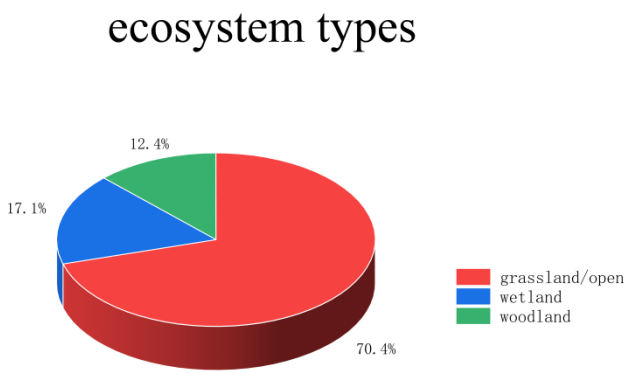

Fig. 8 Number of sites in relation to ecosystem types

The groundwater content at archaeological sites may serve as a limiting factor for the distribution of settlements. The sites do not exhibit a preference for areas with high groundwater productivity, with sites over highly productive aquifers, moderately productive aquifers, and low productivity aquifers accounting for 28.3%, 13.5%, and 16.3% respectively, while sites with essentially no groundwater make up 42% of the total. The low correlation between groundwater and archaeological sites may be attributed to the abundant water resources on the island of Britain. Abundant precipitation and a dense network of rivers rendered the need for groundwater.

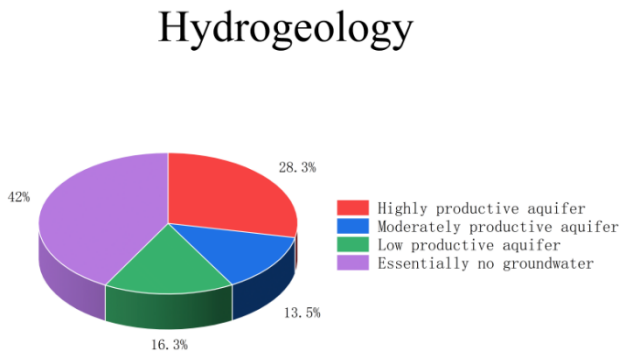

Fig. 9 Number of sites in relation to Hydrogeology

4.5. The impact of water

Adequate water supply is essential for a variety of applications, including agricultural irrigation, industrial production (e.g. the manufacturing of pottery), and the daily drinking and sanitary needs of the residential population. Furthermore, rivers play a significant role in transportation, which was decisive for the prosperity and survival of ancient settlements. In the context of Roman Britain, a strong correlation is evident between the locations of archaeological sites and the availability of water resources. As illustrated in Fig. 10, the histogram indicates that over three-quarters of the archaeological sites are within 1 kilometer of a river (2789 out of 3645), with a small minority of sites (245 out of 3645) being more than 2 kilometers away from the river. This suggests a preference among the inhabitants of Roman Britain for establishing settlements in close proximity to water sources.

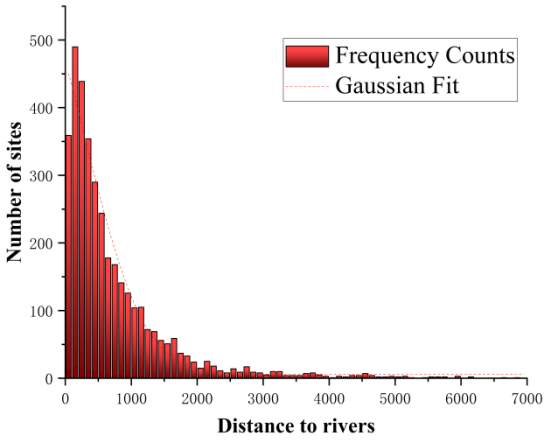

Fig. 10 Number of sites in relative to the rivers (Excluding a subset of sites located on minor islands)

We have surveyed the groundwater content of archaeological sites that are positioned beyond a distance of three kilometers from rivers. As depicted in Figure 9, the majority of archaeological sites distant from rivers are located in areas underlain by highly productive aquifers, indicating that inhabitants could meet their water requirements through the development and utilization of groundwater resources. This suggests that the residents during the period of Roman Britain had a certain level of expertise in the exploitation of groundwater resources, such as the construction of wells and the development of spring water.

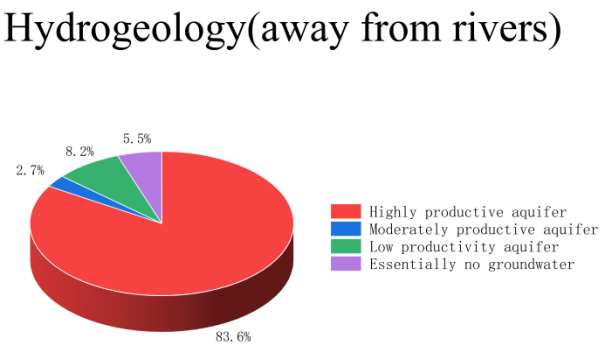

Fig. 11 Number of sites which are away from rivers in relation to Hydrogeology

5. Conclusion

During the Roman Britain period, settlements were predominantly concentrated in the southern and central eastern regions of the British Isles. Particularly in plain areas closed to water sources, the distribution of archaeological sites exhibited a higher density, while in areas of higher elevation, the presence of settlements was significantly scarcer. Furthermore, the high proportion of nucleated settlements and the extensive distribution of religious ritual sites within the settlements reflect, to a certain extent, the profound impact of Roman culture on the social structure and cultural aspects of the British region.

The spatial distribution of coins and pottery, coupled with the results of exploratory regression analysis, demonstrates a strong intercorrelation between economic and cultural activities, further elucidating the significant economic and cultural status of nucleated settlements in Roman Britain.

The natural environment also exerts a significant influence on the distribution of settlements. The site selection for settlements exhibits a clear preference for certain local ecosystem types, with grassland ecosystems being considered the most suitable among them. The availability of water resources also played a pivotal role in the distribution of settlements during the Roman Britain period. The transportation and resource supply advantages of rivers have led to the majority of archaeological sites being distributed near watercourses, while sites situated farther from rivers are often located over high-productivity aquifers, which may indicate the capacity of the inhabitants during the Roman Britain period to utilize groundwater resources.

By employing Geographic Information Systems (GIS) to analyze the relationship between the natural environment and the distribution of ancient sites, this study aims to provide a novel perspective for understanding how ancient societies interacted with their natural surroundings and offers theoretical and methodological support for future similar research endeavors. Due to the use of point feature data in the research, which cannot accurately represent actual surface phenomena, such as the topography surrounding archaeological sites and specific environmental characteristics, the analysis is subject to limitations. Furthermore, contemporary land-use changes and archaeological site preservation

policies across different regions can also impact the accurate revelation of the spatial distribution of archaeological sites, a factor that was overlooked in this study. In future research, it is imperative to consider the integration of a more diverse range of data types and to account for the impact of temporal changes in order to enhance the accuracy of the study.

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