Geostatistical Approach to the Topology of the Prehistoric Settlement System: A Case Study in Musashino Upland, Tokyo, Japan

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Abstract

The purpose of this study is to discuss the prehistoric settlement systems in the view of Geostatistical analytics, and to introduce the theoretical concepts of GIScience into Archaeology. The subject area is the eastern part of the MUSASHINO upland that has an area of approximate 300 square kilometers, with 98 archaeological sites from the middle Jomon period (cal BP. 5400-4500). The population in highest stage of its development is estimated to be 2000. First, database that has a mutual comparability of the space and site's archaeological properties was created. The digital site distribution maps, which can refer to miscellaneous attributes were also created. Then the following three analyses were applied. 1) The Voronoi method (as interpolation) was applied because the geometrical properties of the diagrams symbolize the topological characters. 2) The inter-site visuability was drawn by applying Viewshed Analysis for elucidating the inter-site spatial relations. 3) Trend-surface analysis was enforced using point properties of archaeological cultural elements to reconstruct the spatially concrete images. Finally, the results were lined up along the "unconditional" time-series. Thus, I propose considering this approach as Four-dimensional "4D" GIS.

Introduction

Until recent times, the prehistoric settlement has been discussed from the multifarious point of view in archaeology. In order to reconstruct the human evolution, "Process or Marxism" archaeologists in the 1970s, eagerly argued about the socioeconomic context. But, after 1980s, Many Western archaeologists thought that this approach is insufficient in understanding the human-nature interactions since the settlement reflects human behavior corresponding to the surrounding environments. "New" and "Post-Process" Archaeology were regarded as much important. Spatial archaeology (Clarke 1977) is the one study area developed in this atmosphere. It was the phenomenal challenge toward the old analytics in which any archaeological information was never grasped as spatial attributes.

Such awareness of the issues was gradually adopted by geographers in Japan, although in "Prehistoric Geography" from the 1940s, the systematic linkage of Archaeology and Geography had not been achieved. But, because most of the Japanese archaeologist blindly believed that "Archaeology as Archaeology" based on materialistic data is the only positivistic approach, their potentialities of collaboration have not grown.

In 1990s, GIS developed rapidly by the expansion of PC and GIScience (Geographic Information Sciences; as epochal interdisciplinary studies) was formed. Its application in Archaeology began in 1990s, nevertheless it had not been acknowledged as an effective method, rather it had been thought as a useless tool, for there was no theoretical foundation for processing the spatial information in archaeological methodology with the exception of a few studies (Tsumura 2002). Thus, in this preliminary study, I would like to practically and theoretically organize some former individual approaches by especially focusing on the interdisciplinary perspectives in order to discuss about the prehistoric settlement in the view of Geostatistical analytics as well as introduce the GIScience theoretical concepts into Archaeology.

MUSASHINO Archaeo-Ecological Project

[1] Target Area

The target area is the eastern part of the MUSASHINO upland that has an area of about 300 square kilometers with 98 archaeological sites (see Fig.1, 2).

The palaeo-geomorphologic characteristics of this area are 1) there are less topographic undulations which enormously
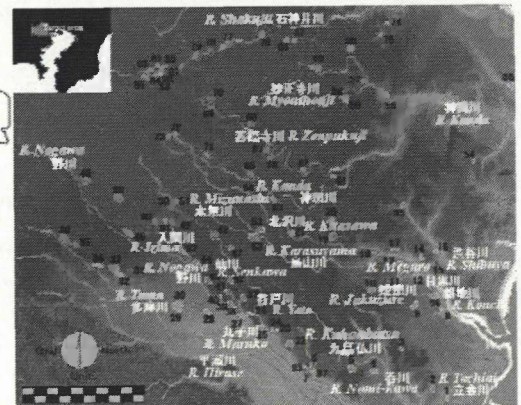

Figure 1 Subject area

Figure 2 Sites distribution and river system map on DEM

influence the human-walking costs compared to other areas. Its mean altitude: 38.59m and standard deviation: 17.79, 2) the slope angle is not so steep, and its slope direction is none (flat) or SE in the area. Its mean angle: 1.81 degrees and standard deviation:

3.55, mean aspect: 139.72 degrees and standard deviation: 98.49, 3) streams or creeks are abundant, and some springs are along the streams, 4) the contrast between upland and lowland where nestle close to the Tama river is very clear and there are many fountains in this area that we call "HAKE".

[2] Digitizing the Site Distribution Maps

For equipping GIS with reference system based on site's archaeological properties and spatial coordinates, I digitized the site distribution maps as polygon data by tracing the usual paper maps with digitizer. I thought that the address matching, which is common method, is unsuitable method, for the old and usual maps were not made by taking its spatial coordinates in to account. In other words, the data recording ways should follow the paper map's methods as well in transcribing, if the observers' judgments about the site area are regarded as important. Since address matching refers to the text form address, the most important information about the locality may be omitted, for many sites are in an out-of-the-way anonymous place.

It is a big issue in how we divide the site area. Since all the sites are not fully excavated, "The site area" (in the strict sense of the word) must be indistinct permanently (Tsumura 2002). I considered the investigator's assessment is the most important information; there adopted "The potential site area" (estimated by Kobayashi et al. 2002) as "The virtual site area". This approach is very simple and unpolished, but most certain in converting the raw archaeological information into digital form.

[3] Digitizing the other spatial element maps and constructing the database with reference system

I digitized the other spatial elements, such as river system as a line data and soil system as a polygon data. Fundamentally, we should reconstruct the palaeo-environment by some appropriate methods, but it is very difficult with GIS technology at present due to a massive alluvial soil cover (Tsumura 2002).

The digital maps of spatial elements, which has each spatial coordinates, or the site digital distribution maps were combined with archaeological properties by GIS technology with the original discrimination IDs. The mutual references, spatial attributes from/to site's properties, were made possible, and this system made many digital site distribution maps.

Large quantity of digital maps were arranged along the calibrated radiocarbon date "cal BC" to clarify the temporal transitions of human activities. This approach will promise sublimation to the next stage of archaeological studies with the biological perspectives from the old style that slipped into the materialistic view of history. For the former relative timescale could only make a static cultural image.
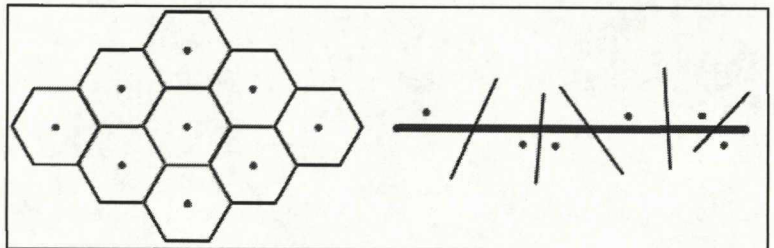

Figure 3 Models of Voronoi Diagrams Left: Hexagonal diagrams, Right: Distorted diagrams

GEOSTATISTICAL APPROACH 1 - VORONOI METHOD

[1] Making the Voronoi Diagrams

The Voronoi method is one of the interpolation techniques in Geometry. Its diagrams can indirectly express the properties about the topology of the spatial objects. For example, a set of hexagonal diagrams indicates that these objects are being uniformly distributed, or a set of distorted diagrams may mean that these objects are spatially influenced by some other dimensional spatial attributes (see Fig.3). Therefore, in order to know the spatial behaviors of prehistoric human societies, the inter-site relations will become clear along the time-series by using many digital site distribution maps with "cal BC", if the Voronoi diagrams that based on each locations of the archaeological site are illustrated.
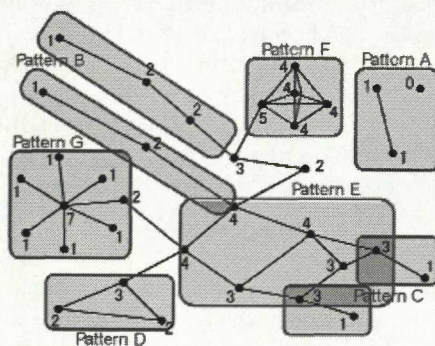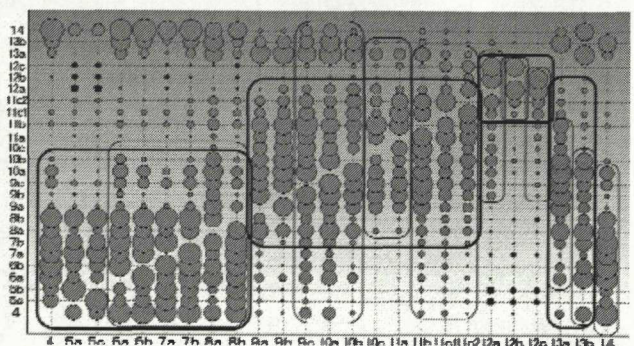

Figure 4 Inter-site visuability patterns

Figure 5 Graphic chart of the visuability patterns determinant

[2] The Voronoi Diagrams

The Voronoi diagrams are extracted by

i. The straight lines are drawn between each object.
ii. Its vertical bisector is drawn as far as their intersections.
iii. The inside area of these is made the connections to the

object as a polygon. This method has been well applied for the analytics of marketing or ecological area because of iii. I analyzed the site distribution maps with this method (Fig.6).
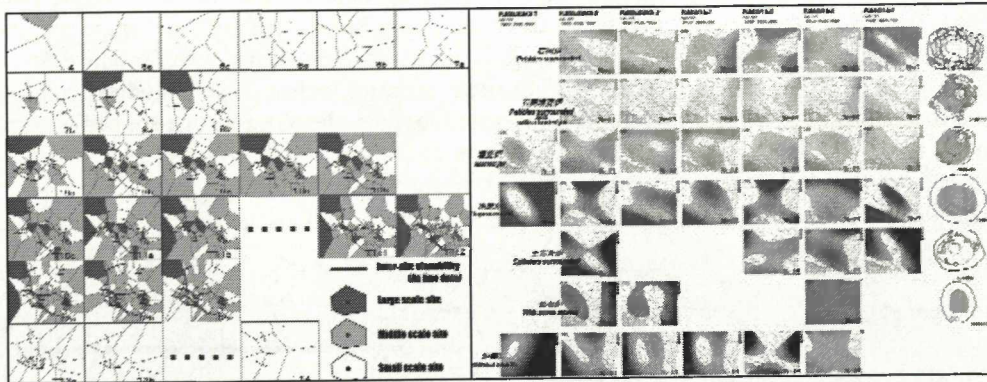

Figure 6 Voronoi Diagrams and inter-site visuability lines

Figure 7 Trend-surfaces of various hearths' composition ratio

GEOSTATISTICAL APPROACH 2 - VIEWSHED ANALYSIS

[1] What is the Viewshed Analysis?

The Viewshed analysis is a method to extract all visible area from the whole target area based on relations between the view point and the angle of elevation. In GIS technology, this process is executed based on DEM. Although this approach may have some problems (e.g. a huge gap of the assessment of data and the interpretation), it illustrates the actual images of the prehistoric human spatial interactions.

[2] Describing the Inter-Site Visuability

In assessing the inter-site visuabilities, histograms on the number of visuable or unvisuable relations were made, for these spatial topologies of visuabilities can be classed by these statistical quantities (see Fig.4). For instance, when its mode is 2 or 3, its topology of inter-site conjunctions will look like a line or a circle (Pattern A, B or D). Similarly, when its mode is 4 or 5, or its standard deviation is smaller, it will look like 2D or 3D web (Pattern E or F). More over, when its maximum and minimum value gap is large, it will look like a spokes of a wheel (Pattern G). We have only to assess its patterns that were modeled from some inter-site visuabilities to reconstruct the prehistoric human-human interactions.

As a result of this approach, it became clear that the inter-site relations of the target area gradually became complicated from pattern A to B, to C/D, to E/F, to G (Tsumura et al. 2002). This pattern show that the prehistoric peoples not only had decided their settlement locations based on natural environmental elements, but also made decisions under the pressure of their own social interactions. If they decided freely, their settlements would have been accumulated on the same place where the natural environmental condition is most suitable.

Finally, I computed the visuability determinant patterns from correlation coefficients, and created the graphic chart (Fig.5). It is clear that several epochs would be extracted for explanation about human social evolution from this result.

[3] The spatial correlations between the Voronoi Diagrams and the inter-site visuability patterns

To examine the spatio-temporal relations between site locations and their own relations, the inter-site visuability lines that were reconstructed in chapter 4.2 were overlaid on the Voronoi diagrams along the time-series (Fig.6). It is clear that the former traditional explanations, for example, these prehistoric dwellings were being arranged with spatial uniformity to avoid intervention, has some problems, for there are many diagrams more distorted than hexagonal in any phases. And we will also become aware the other old explanations about site locations, such as "Its decision makings might be influenced by the existence of rivers or springs" are not necessarily so simple. Instead this analysis made it clear that the site location and area had been connected with their own spatial interactions. This method made possible to create some concrete images about the inter-site relations as a linear situation and elucidated a mechanism that lies behind making decisions on site location with the geometrical character of diagrams that symbolize the topological characters.

GEOSTATISTICAL APPROACH 3 - TREND SURFACE ANALYSIS

[1] The Keys of Trend Surface Analysis

The trend surface analysis is one of the Geostatistical methods that assess the spatial tendency in vector field such as directivity or intensity of subjects from several spatially dotted attributes. If we were to apply this approach to the archaeological spatial analytics, several archaeological cultural elements will play the mouthpieces of their own prehistoric social contexts. Presupposing this idea, pottery, hearths, and lithic types were adopted as archaeological elements. Pottery types' trend surface will indicate an inter-site trading system because pottery were conventionally a movable cultural attributes. Hearth types' trend surface will show matrimony system since conventionally woman had managed hearths. And lithic types' trend surface will reconstruct the spatial expansion of various subsistence. With GIS technology, we would be able to explain several spatial interactions or correlations about material culture elements left by human activities in various contexts in high probability.

[2] The Trend Surface Analysis

The trend surface are computed by
i.   LINEAR $z = b_0 + b_1 x + b_2 y$,
ii. QUADRATIC $z = b_0 + b_1 x + b_2 y + b_3 x^2 + b_4 xy + b_5 y^2$,
iii. CUBIC $z = b_0 + b_1 x + b_2 y + b_3 x^2 + b_4 xy + b_5 y^2 + b_6 x^3 + b_7 x^2 y + b_8 xy^2 + b_9 y^3$,

I sorted out a suitable object from these results by the goodness of fit and F ratios. These trend surfaces were arranged along the "unconditional" time-series (e.g. in case of hearth types', see Fig.7).

As a result of the analysis, I could suggest the following; 1) the spatial deviation of trend surfaces of hearth types is larger than pottery, 2) in case of the trend surfaces of hearth types, there are several small centers (peaks) of directivity and/or intensity, 3) these results of 1 and 2 reflect the spatial characteristics of cultural elements, namely, movable (like pottery) or un-movable (like hearths), 4) an appropriateness of the spatio-temporal complex could be reconfirmed as a conceptual premise in archaeology that is the multiple spatial layer of infinite dimensions.
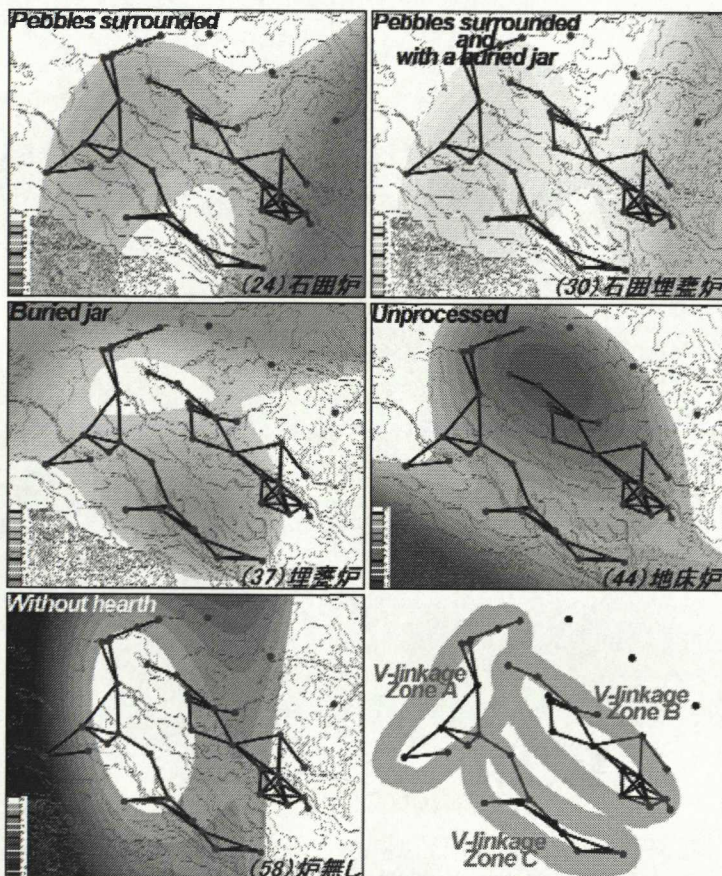

Figure 8 Spatial correlations between trend-surfaces and inter-site visuability lines

[3] Spatial Correlations within the Cultural Elements

Finally, to detect more concrete correlations from these spatiotemporal complexities, I unfolded the inter-site visuability patterns on these trend surfaces (see Fig.8) using the overlay analysis. As a result, there were positive correlations between them. In this case, the visuability linkages that are zoned by its spatial density (: V-linkage zone) were well matched with the hearth types trend surfaces. The V-linkage zone A correlates closely with the pebble-surrounded hearth' trend surface, the V-linkage zone B has a mutual relation to the unprocessed hearth's trend surface, and the V-linkage zone C has an interrelation with the buried-jar hearth's trend surface.

Therefore, we can see that the distribution of the sites might have been decided with the inter-site visuability based on their matrimony system. For example, a system of marriage in which the wife visits the husband at his home, and its spatio-temporal complexities were gradually became complicated. Although this conclusion is very simplified, at least, we would be able to understand that these spatial situations have not occurred by simple one spatial context like a "Water supply".

CONCLUSION - REAL ABILITY OF GIS TECHNOLOGY

Finally, Voronoi diagrams, inter-site visuability lines, and trend surfaces of cultural elements were lined up along the "Unconditional" calBC time-series. The interpolation of temporal gap was morphed by leaping. This approach made clear the dynamism of culture.

By applying the GIScience in archaeological spatial analysis, I was able to approach "eloquently" to the prehistoric human spatial activities through several "silent" material cultures. These are new methodologies that are neither "Geo-Archaeology" nor "Prehistoric Geography". I would like to propose this methodology as "Time-GIS" or "Four-dimensional GIS". The real abilities of GIS are to treat much interdisciplinary information founded on unified systems, to compute much-complicated statistical problems, and to show the process of "eloquent" reconstruction of the human history.

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