Geographical Analyses on Distribution of Archeological Sites of Village and Hill-fort

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This paper treats the relation between two kinds of important sites of ancient Japan, in the Late Yayoi period (100-300AD), by using a geographical information system. One is a group of village sites which existed through the period. Another is a group of hill-fort sites with beacon facilities. The authors have already shown a network of interrelation between village sites, which showed a sort of connection between sites from the viewpoint of *cost of movement*. On the other hand, ancient communication networks have been given between hill-fort sites based on visibility between them. Integrating these independent researches, this paper presents an analysis on the geographical distribution of both types of sites. We take the sample sites within a special region for simulation, which are distributed along Yodo River in Osaka and Kyoto Prefectures. We could obtain good understanding of mutual relations between villages and hill-forts.

1. Introduction

Archaeology is regarded as a science to restore lives and societies of ancient people, based on the knowledge acquired from excavation. It has also been well recognized that geographical information plays an important role in archaeology. In fact, archaeologists have been drawing various kinds of maps by hand to understand the past; in other words, those maps have been drawn for geographic analyses on many types of distributions of archaeological sites. Unfortunately, such a traditional way without computers would not provide more than existing limited types of geographic analyses. In contrast, there would be much room to provide a variety of geographic analyses to be offered in the progress of the information technology (IT). Especially, geographical information system (GIS) looks very powerful for geographic analyses on distribution of sites by linking it to 3-dimensional terrain data. We have developed a GIS specialized for geographic analysis on the Late Yayoi Period (100AD-300AD), which consists of two types of databases and their managing system; one is an archaeological database of ancient village sites in the period and another is the digital terrain database. We call it the four-dimensional historical space system (FHSS). This paper treats quantitative analyses on the relationship between two kinds of village sites in the period, which are carried out by using FHSS.

Village sites in the Yayoi period have been classified into two types; i.e. nucleus village sites and hill-fort sites. Every nucleus village site is large-scale, extending around the center in a flat land in an area. On the other hand, hill-fort sites were small-scale, situated at altitude, some of which are estimated to be equipped with beacon facilities for military telecommunication. Archaeological knowledge is that both types of sites existed in the same area and at the same time. We have a hypothesis that a number of hill-forts

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were associated with a nucleus village. Though it has not been verified by quantitative analysis yet.

In this paper, hill-fort sites to be estimated as closely connected to nucleus villages have been shown, which are extracted by using FHSS. It is also important how to show detected relations between sites clearly on the display. This paper presents a style of representation to show such geographic relations.

2. NUCLEUS VILLAGE SITES AND HILL-FORT SITES

Almost all of the Yayoi villages were extended over a flat land or over a low hill near the water for managing paddy fields. A nucleus village is the large-scaled village, which was located at the center of an area and, in most cases, continued for a long time [1,2]. A nucleus village was associated with many small villages and facilities. Nucleus village sites have mainly been detected in the western part of Japan. Fig. 1 shows a distribution map drawn by an archaeologist, illustrating relations between nucleus village sites in the central area in the Kinki region [1,3]. 54 nucleus village sites appear in Fig. 1.

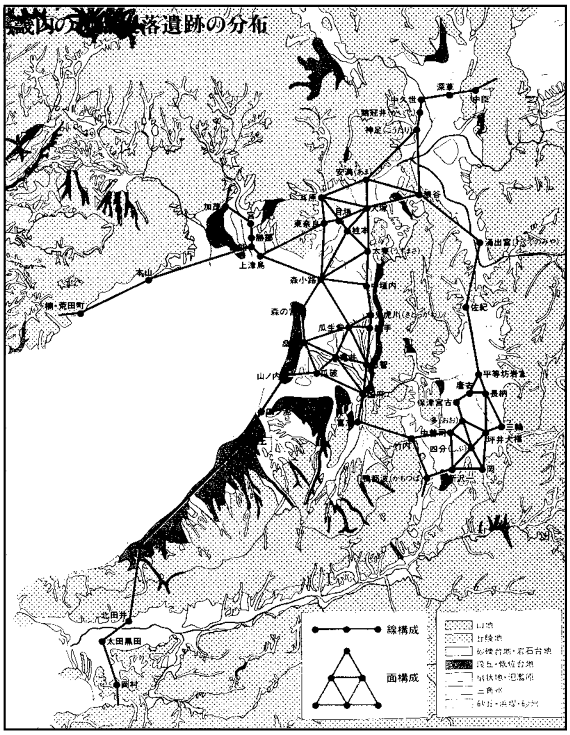

Fig. 1 Distribution of nucleus village sites.

On the other hand, many hill-fort sites have been excavated at altitudes higher than 100 meters in western Japan, which would seem to be unsuitable places for managing paddy fields. Hill-forts continued to exist between the Middle and Late Yayoi periods, the age of war, referred to as "the Great Japanese Civil War" in an ancient Chinese document. An archaeological hypothesis is that hill-forts were equipped with beacon telecommunication facilities [4,5,6]. This has been derived from their strange locations and the historical background. This has been verified in earlier field experiments of beacon telecommunication between a small number of hill-fort sites by a group of archaeologists. In the experiments, they produced smoke coiling up at the sites. Fig. 2 shows the result of visibility of smoke between the sites [4].

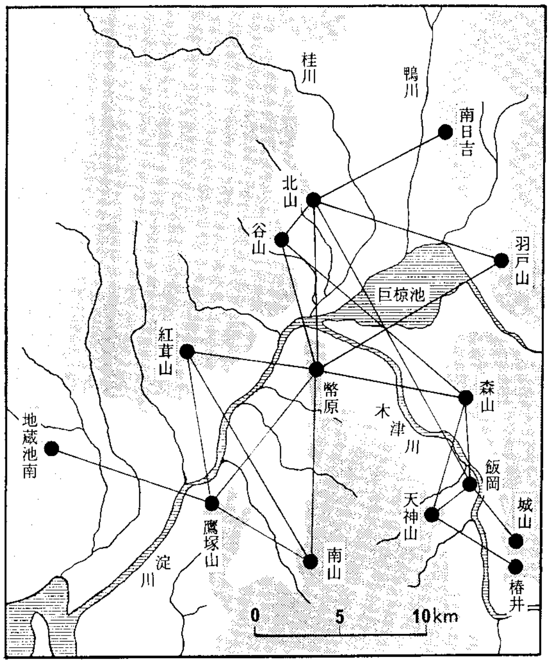

Fig. 2 Visibility network given by a field experiment.

3. NETWORK MODELS

We introduce two types of network models to consider the relationship between nucleus villages and hill-forts [7,8,9,10].

Both models have been presented based on different purposes, respectively. They have already been implemented as key functions of FHSS, supporting to archaeological network analyses. Some of the analyses presented in this paper have been obtained by using FHSS. Fig. 3 is an example of maps displayed by FHSS.

A. Village network model of nucleus village sites

The first model, termed *village network model*, is defined to extract networks consisting of routes for cultural exchange between nucleus villages. Cultural exchange would take place on a basis of movement of people: Since roads are basic facilities for their movement, our village network model is defined as a macroscopic model showing what roads or routes should exist between nucleus village sites.

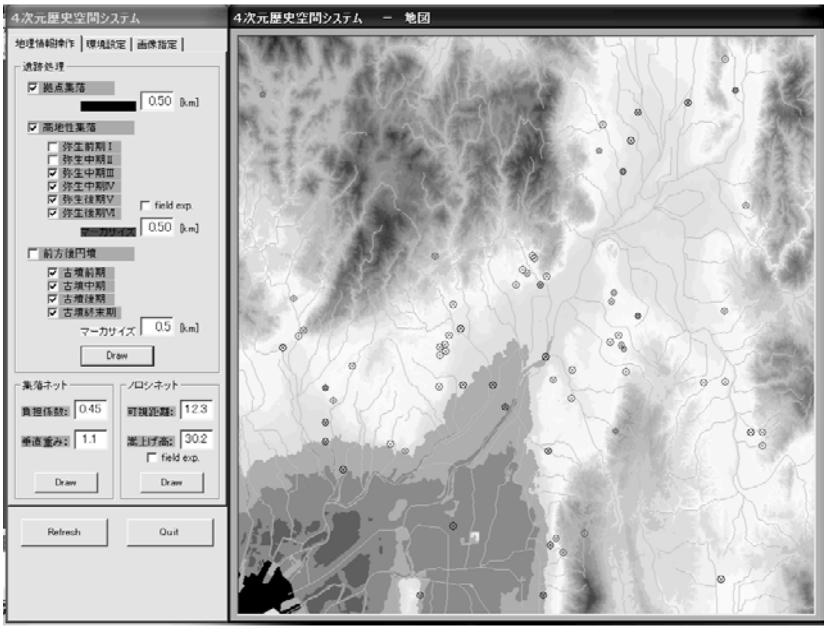

Fig. 3 A display image of the four-dimensional historical space system (FHSS).

In general, there are numerous possible routes to link two distant sites; a route is given by a collection of roads to link intermediate sites one after another. We guess that the main route between two distant sites should be one with the minimum *cost* among such possible routes as above. Here, we introduce the cost function for movement of people as follows:

Let $f(x)$ be cost of movement, x be moving distance and k be a constant. Then we have

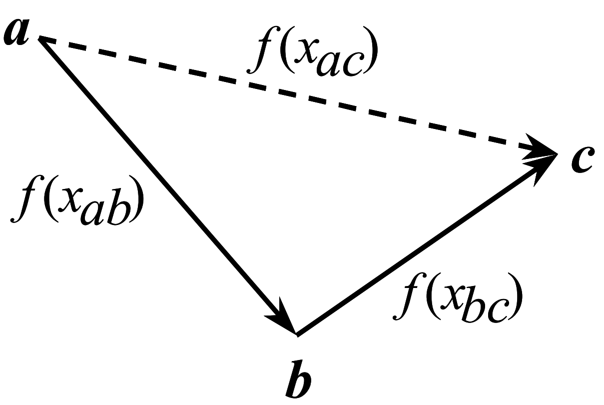

Fig. 4 Routes and Costs.

$$d_{ab} = 4, d_{bc} = 5, d_{ac} = 6$$
$$f(d) = d : 9 = c_{ab} + c_{bc} > c_{ac} = 6$$
$$f(d) = \exp(d) : 203 \approx c_{ab} + c_{bc} < c_{ac} \approx 403$$

$$\frac{\partial f(x)}{\partial x} = kf(x). \quad (1)$$

A general solution of this equation is given by

$$f(x) = C\exp(kx). \quad (2)$$

Where C is a constant. $\exp(\cdot)$ denotes exponential function with base e. We assume C=1. It means that the smaller $f(x)$ is, the easier people move. $k(>0)$ means a value which controls difficulty of movement. k has been playing an important role in determining routes (See Fig. 4). The village network is obtained by overlapping the radiate networks each of which is defined by one with the minimum cost from each village site to all of the others (See Fig. 5). Search for the minimum cost route is done by using an algorithm to find the shortest path.

B. Beacon telecommunication network model of hill-forts

The second is the *beacon telecommunication network model*. This model confirms the hypothesis that hill-forts were equipped with beacon facilities. By using FHSS, a beacon telecommunication network between hill-forts has been detected; visibility between the sites has been verified based on the 3-dimensional terrain database. The result is approximately the same as that of a field experiment done by a group of archeologists as previously mentioned. Practically, our verification has been carried out by examining visibility between every pair of sites; i.e. we examine for visibility, whether a site can be seen from another site without geographical obstacle.

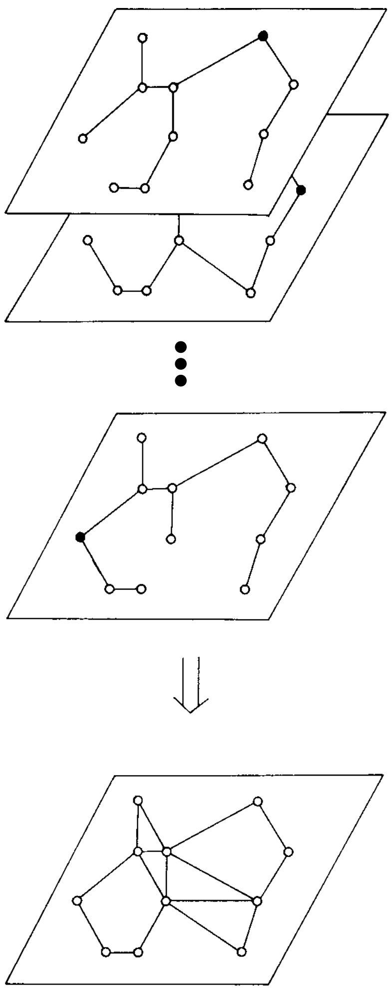

Fig. 5 Overlapping networks.

The network has been defined by connecting "visibility relations" between the sites. The digital terrain data consisted of 50×50 meters blocks provided by the Japan Geographical Survey Institute [11]. An altitude value for a block is quantized at a 10cm interval. FHSS has two parameters; i.e. *visibility range h* and *height of stand r*. Visibility range is nothing but the maximum distance at which people in a hill-fort could recognize smoke coiling up from another distant place. Height of stand means height of the smoking stand or watching stand in a hill-fort. It has been added to altitude of each hill-fort sites in the computing process of FHSS, acting to eliminate some kinds of effects in relation to the quantized altitudes of digital terrain data. Here, we omit some of the more detailed description of technical procedure to examine visibility between two sites. Fig. 6 illustrates our procedure to examine the visibility.

4. ANALYSES ON GEOGRAPHICAL DISTRIBUTION OF SITES

Our analysis on geographical distribution of nucleus village sites and hill-fort sites starts with a definition of the network described previously. An example of the region for our experiment is a 40 km×40km square region including *Yodo Rive*r running over both Kyoto and Osaka Prefectures. There are 24 nucleus village sites and 14

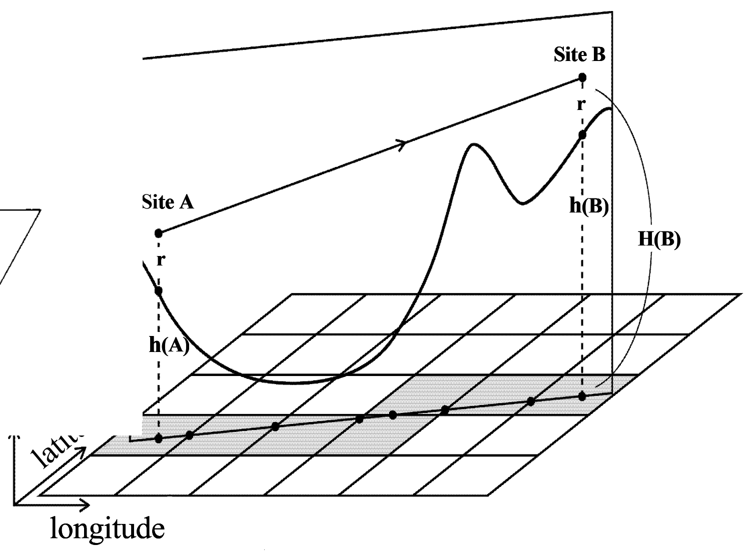

Fig. 6 Examination of visibility.

hill-fort sites in this region as shown in Fig. 1 and Fig. 2, respectively.

A. Distribution of sites

The village network of nucleus village sites has been defined by k= 0.4 in (2). This value is set by trial-and-error to obtain a network most similar to that of Fig. 1. The network is shown by dark lines in Fig. 7, which is slightly different from that of Fig. 1. This might be caused by the absence of some sites in Fig. 1.

In order to establish obtain the beacon telecommunication network between hill-fort sites, we set the two parameters as h=12.3km and r= 30.2m, respectively. Those values are set in order to remove the long lines from Fig. 2. Fig. 7 is a display image of FHSS, overlapping two kinds of networks. A small circle indicates position of a site. The village network is drawn in dark (blue) lines and the beacon network in bright (red) lines.

Fig. 8 Representation of village sites by circle. In Fig. 7, we can recognize that three of the hill-fort sites are very distant from nucleus villages and the village network. In contrast, since the other 11 hill-fort sites are fairly close to nucleus village sites, they are regarded as being closely connected to nucleus villages.

B. Neighboring sites

We next estimate which nucleus village site relates to which hill-fort sites by considering distances between the sites which are connected in the village network as given above. Each village would have an extent of its territory. Simply, we assume that the boundary between two sites is the middle of both centers. Then, we also assume that every hill-fort site related to its nucleus village site should be within a circle area, around the center, within a radius of half of the distance from the neighboring village.

The mean distance between nucleus village sites of the network in Fig. 7 is computed as 5.48km. Fig. 8 shows a map given by drawing a circle, diameter 5.5km

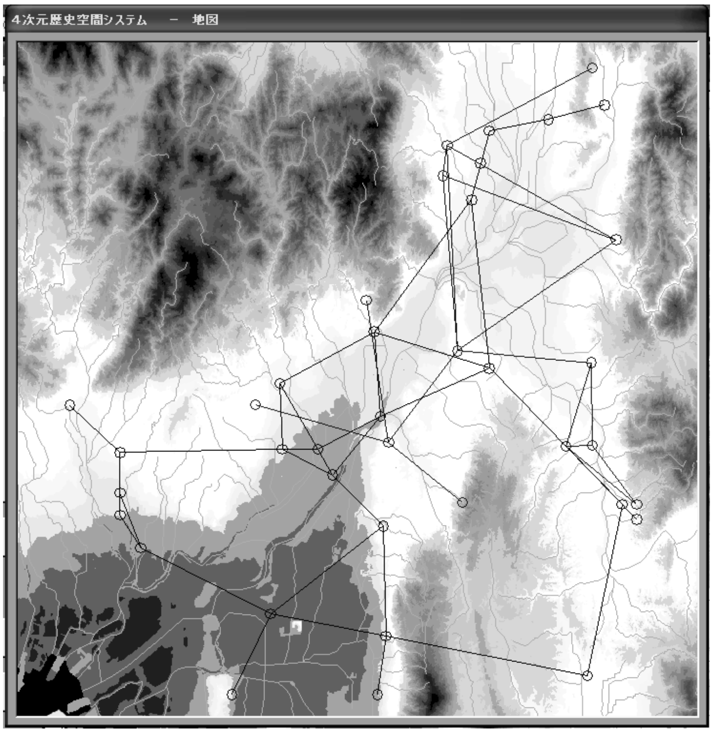

Fig. 7 Two Networks.

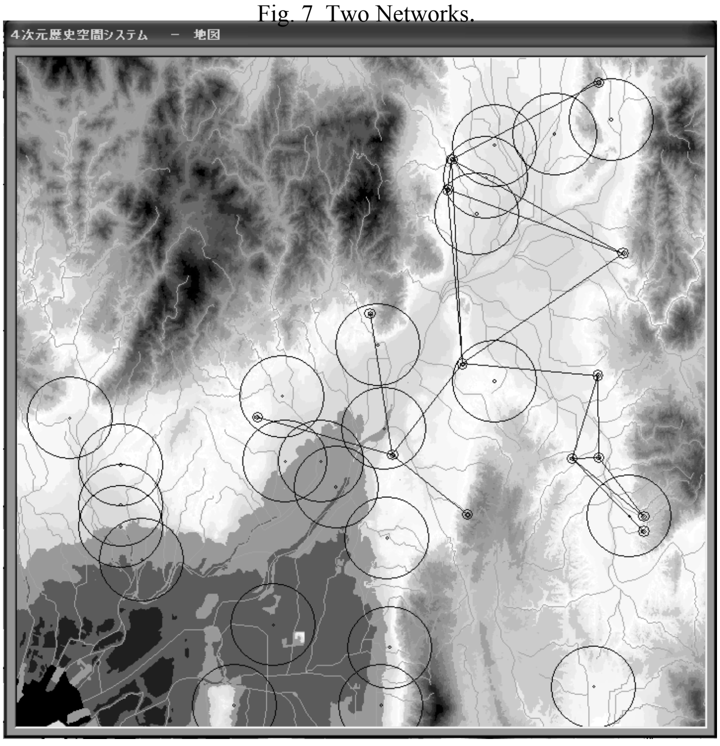

Fig. 8 Representation of village sites by circles.

for each nucleus village. The beacon telecommunication network is also drawn to give references for our estimations. From Fig. 8, we can find that two types of hill-fort sites exist in the map; one is near the circles and another is away from the circles.

The first type includes nine sites and the second includes five sites. Hereinafter, we will take only the first type of nine sites for our consideration.

C. Analysis on distances between hill-fort and nucleus village sites

We can estimate how each of the nine hill-fort sites specified above should be related to which nucleus village site. In Table 1, 11 pairs of nucleus villages and hill-forts are listed, which are very closely connected in terms of distance. Those pairs are candidates to look for archaeological binary relations such as “a hill-fort is associated with a nucleus village”.

From Table 1, we have established the mean distance between a pair of sites as 2.49km, and its standard deviation is 0.17km. Inspecting Table 1 in detail, we can find that two distances (Wakudenomiya - Shiroyama, Wakudemiya - Tsubai) are extremely small. Wakudenomiya, a common nucleus village, is located in a special place in terms of geographical features (See Fig. 8 and 9). Then we estimate that these two pairs of sites are very special compared with others. Then excluding these two pairs related to Wakudenomiya, we compute the mean distance and standard deviation for nine pairs; i.e. 2.49km and 0.09km, respectively.

D. Estimation of extents of hill-forts

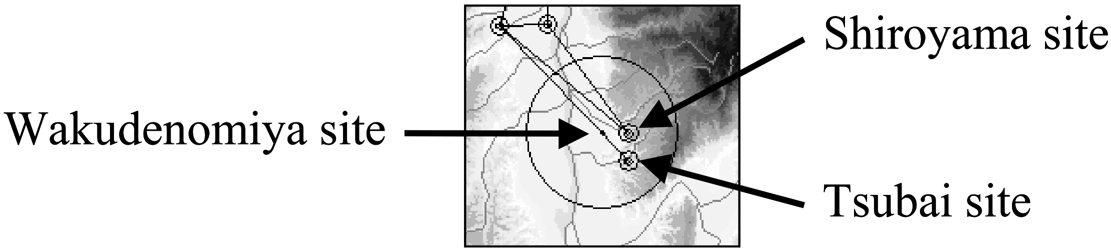

Fig. 9 A magnified map

Table 1 Distances between pairs of sites.

Nucleus village sites	Hill-fort sites	Distance [km]
Nakatomi	Minamihiyoshi	2.74
Nkakuze	Kitayama	2.97
Kaide	Kitayama	2.55
Kaide	Taniyama	2.66
Kotari	Taniyama	2.57
Okamedani	Hidehara	2.42
Ama	Benitakeyama	2.27
Ootsuka	Takatukayama	2.02
Mimihara	Jizouikeminami	2.25
Shiroyama	Wakudenomiya	0.96
Tsubai	Wakudenomiya	1.48

A hill-fort site is estimated to be within the circle-shaped area with diameters less than 5.5km and larger than 4.5km around the center of its nucleus village. These diameters are defined by adding three times the standard deviation to the mean distance of the nine pairs of sites. Fig. 10 shows the display image of FHSS locations of the 11 sites. We can see that seven hill-fort sites are located within the gap of the double circles, three sites are within the smaller circle and a site exists out side of the larger circle.

A hill-fort site, Kitayama site, located outside of the larger circle might not be connected to the nearest nucleus village site (Nakakuze site). On the other hand, Kitayama is also a member of a pair with Kaide. We can estimate that there would be a stronger relation between Kaide and Kitayama than between Nakakuze and Kitayama. Because it is within the gap area of the double circles (See Fig. 11).

5. ARCHAEOLOGICAL CONSIDERATION

This paper presents an experimental result by FHSS, aiming at examining the archaeological hypothesis that hill-fort sites are associated with their nucleus villages. We need much more time to conclude whether or not our result could open the door to a new understanding of distribution of archaeological sites. R. Sakai who drew Fig. 2 also presented Fig. 12 to illustrate a model of the basic structure of a nucleus village [2]. It shows that a nucleus village should be divided in to the basic living area, a surrounding space, a function space,

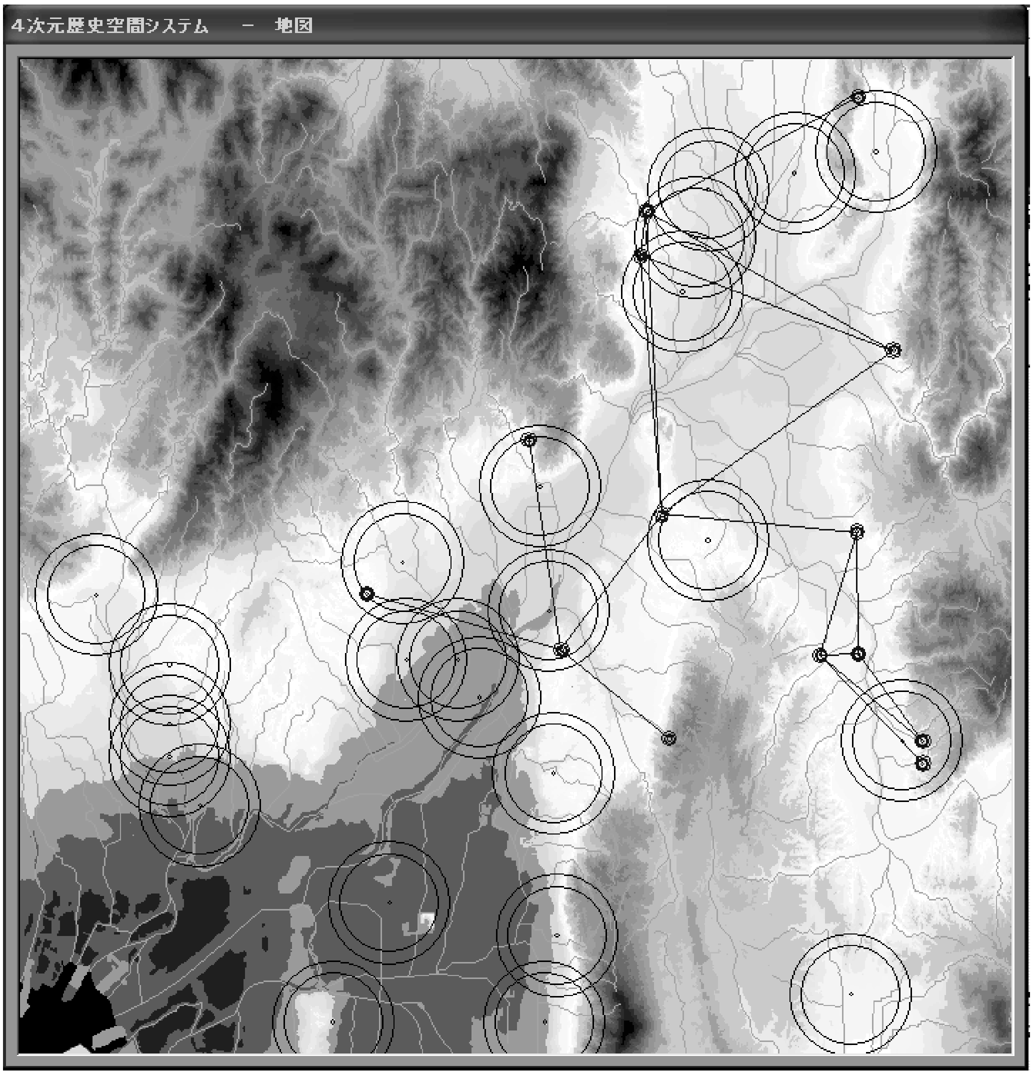

Fig. 10 Distribution of sites on the terrain map.

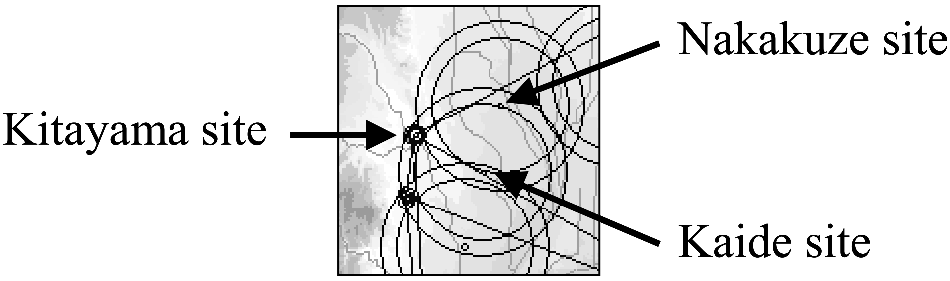

Fig. 11 A magnified map.

cemeteries, a daily activity space, roads and the external space, each of which are drawn by different types of circles, respectively. He estimates that the radius of the function space is larger than 300m and less than 500m. The radius of the daily activity space is estimated to be 5km.

Linking our result with this model, a hill-fort site can be regarded to be located in the daily activity space. This means that hill-forts were not located in the external space, rather were within the area where people in a nucleus village could go and come back to daily. Our result should be verified by many more experiments carried out at a large number of sites. At least, we estimate that a hill-fort was constructed according to a sort of standard; every site is located at a similar distance from the center of its nucleus village site. From this, we might obtain such a suggestion as supporting the archaeological hypothesis that hill-forts were constructed for military purposes. Of course, to substantiate the conclusion, it should be required to verify it by archaeological researches including excavation.

6. CONCLUSION

This paper presents GIS-based analyses on the geographic distribution of a set of Yayoi village and hill-fort sites. One of the results is that several pairs of familiar sites have been extracted based on the distance measure defined between sites. It looks approximately consistent with the existing archaeological understanding. Especially we note another result that almost all the hill-fort sites are located at a constant distance from their nucleus village sites. This shows that our expression of extent of a site, given by a circle, would be effective to detect relations between sites. On the other hand, there still remain many problems to be considered; region-dependent characteristics of sites and time-dependent gaps between the ancient and present terrains. In addition, we still have some future problems concerning the distance measure introduced in this paper.

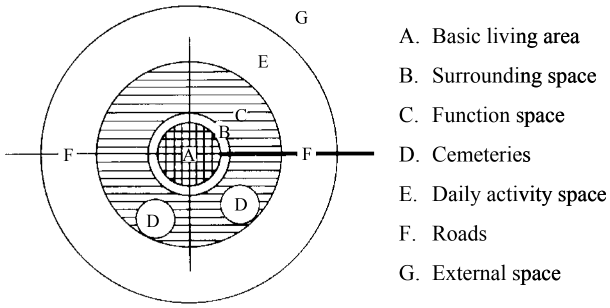

Fig. 12 Basic structure of a nucleus site.

This work was supported in part by the Japan Society for the Promotion of Science under Grant-in-Aid Scientific Research (C) (2) No.12680426.

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